THE MORPHOLOGY OF THE CARPUS AND THE TARSUS.

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THE MORPHOLOGY OF THE CARPUS AND TARSUS.

There is no subject, in the realm of Comparative Anatomy, which has attracted so much attention as that of the homologisation of limb structures.

The number of contributors to this field of research is only equalled by the number and variety of their hypotheses and theories. Results and speculations are so varied in their character, that one is tempted to indorse the remarks of Holl, who wrote in 1891, "the attempts to bring about a homologisation of the constituent parts of the upper and lower extremities had completely miscarried".

When one glances at the list of names of the exponents of the subject, and when one compares their views, and the disparity of their results and conclusions, one realises how futile it is to attempt to gain

anything like a definite solution of the problem.

Turning to the study of the comparative anatomy of the carpal and tarsal segments of the ext - remities, the mass of literature, which presents itself for examination is practically unparalleled in any other field of anatomical research. Hardly a compar- ative anatomist of any note, since 1864 when Gegenbaur published his classical memoir, but has contributed a voluminous quota to swell the mass of already recog - nised fact.

The subject is eminently adapted for phil -osophical speculation, and has been fully taken advant -age of in this direction. It is assuredly a diffi- cult one, and its complexity is added to, in no small degree, by the circumstance that even before the time of Gegenbaur, the subject had attracted a large amount of attention.

Owen gives the priority over all other

inquirers in this region to Vicq D'Azyr, who in 1774 discoursed on the Parallelism of the Bones of the Extremities. "He was the first anatomist whose attention was so much awakened by the perception of these serial correspondences, at least in the human frame, as to have led him to pursue them in detail."

From 1774 to 1857 one finds the primitive history of limb structures discussed by Soemmering, Goethe, Meckel, De Blainville, Barclay, Blandin, Gerdy, Bourgery, Cruveilhier, Turenne, Flourens, Rigaud, Lavocat, Chavveau. Martins in 1857 published a full list of the papers up to his time. This brings us to the period of Gegenbaur with whose work the foundation of the more modern researches begins.

Even a superficial scrutiny of this work indicates to the observer, that to prove of any benefit the subject must be approached from the point of view

of an enquiry into the constitution of the Carpus and Tarsus in the lower vertebrate forms. It emphasises the fact that erroneous views have been arrived at, and promulgated, through commencing with the hypothesis that the human carpus or tarsus is the foundation form. Recognition of the various adaptations which the limbs have undergone, in relation to their functions, is absolutely essential, for as Wiedersheim says "if the fore - limb has been transformed from an ambulatory to a prehensile organ, the hind limb has already reached a third stage in progressive modification- as having first served for support and locomotion, it next became trans - formed into a grasping organ (as is proved by the musculature of the sole of the foot, and by the ape-like opposable condition of the great toe during foetal life) and finally on the assumption of the upright gait it

has changed back into an ambulatory appendage".

All investigations must be begun at the bottom of the vertebrate group, and must be worked through until they culminate in man at the summit of that series. The discussion cannot be limited by a determination of the homologies of the different elements, but must also take into consideration the original number and arrangement of the constituent parts.

One must therefore endeavour to determine

1 The primary number of the bones.

2 The primary arrangement.

3 The homologies.

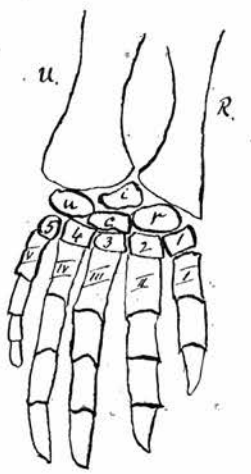
In answering these queries the developmental history of the carpus and tarsus is bound to shed some light on the problem; indeed, it may go far towards the solution of it, when the embryology of the whole vert-

ebrate series can be synopsised.

Gegenbaur begins his investigations with a consideration of the conditions existent in the Amphibian and Reptilian groups. He then proceeds to the examination of birds and mammals, and comes to the conclusion, that he has been dealing with a progressive series of developmental processes. These processes began in the flat mosaic-like portions of cartilage, bound together without joints, which constituted the carpus and tarsus of the amphibia, and terminated in the complex and intricate series of bones and articulations of the higher vertebrata.

The primary number of the bones.

Gegenbaur from his investigations constructed a type carpus, which he found existent and unmod-ified in the water tortoise -Chelydra serpentina.



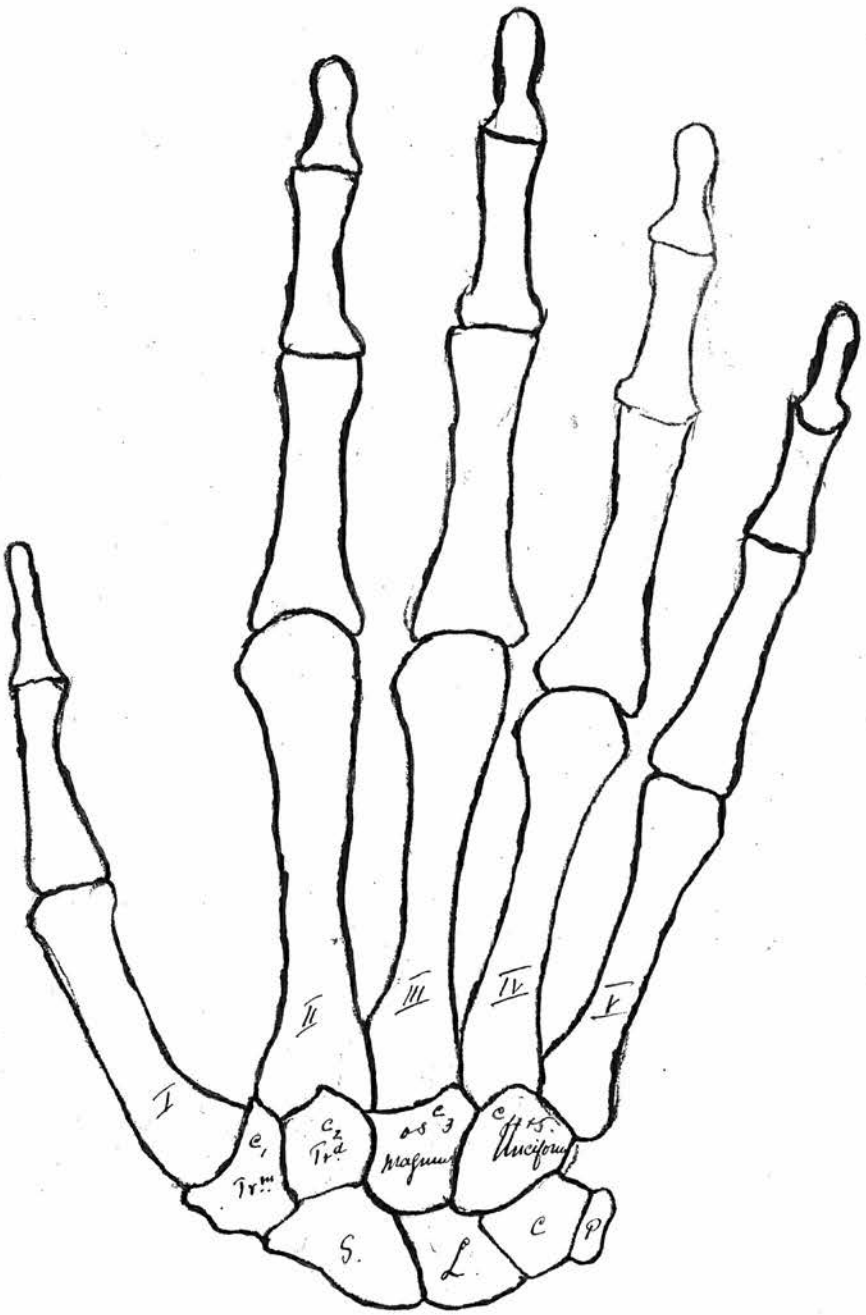
Hand of Chelydra serpentina (Gegenbaur).

This typical or foundational form consisted of nine bones. The derivation of any carpus from this is a comparatively simple matter, and is produced by the suppression of one or other of the primary parts, or it may be brought about by the fusion of two or more of these factors.

Taking it for granted that Gegenbaur's statement is a correct one, for all general purposes, we can see how the mammalian form has taken its departure from the type. The names of the primary elements may be stated as follows -

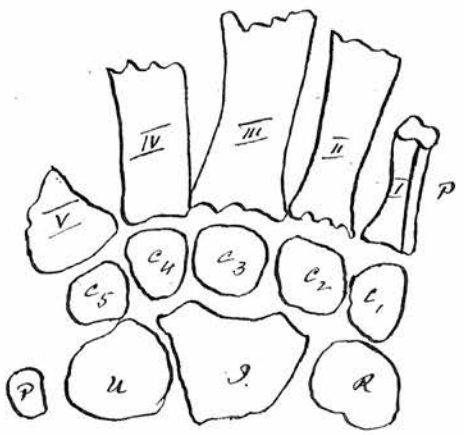
Scaphoid or navicular.
Semilunar or lunatum.
Cuneiform, triquetrum, or pyramidale.
Pisiform.
Trapezium or multangulum majus.
Trapezoid or multangulum minus.
Os magnum or capitatum.
Unciform or hamatum.

Glancing at the carpus in man, one at



Human hand from the dorsum.

once recognises that the scaphoid, lunatum, cuneiform, and the pisiform, are present in a practically unmodified state; whilst the remaining four bones which constitute the carpalia 1 - 4, differ from the type in being four in number and not five. A reduction, then has taken place in the human subject, and amongst mammalia generally only four carpalia are in existence. The type shows that each metacarpal is placed upon its own carpal , but an examination of the mammalian form indicates that the fourth and fifth metacarpals are supported by one carpal. It follows that the last carpal of the series must represent carpalia 4 & 5, of the type form, or that it is merely carpale 4 whilst carpale 5 has been suppressed. Gegenbaur believed that the presence of only four carpalia was a definite mammalian characteristic, having no analogy with the condition found in the amphibia and



Surface of Manus (without the phalanges) in Hyperoodon rostratus. (Turner)

and the reptilia. He asserted that this feature was true for the whole mammalian group, and this was a generally accepted dictum until Sir William Turner in 1885, and Bardeleben in the same year demonstrated the existence of five carpalia in the carpus of the cetacean - Hyperoodon. Turner says that the carpus examined by him was obviously that of an adult specimen of Hyperoodon rostratus. It presented five distinct carpalia, each one associated with the metacarpal of its corresponding digit. The arrangement was not confined to one hand, but was similar in both manus. At the time of writing Turner says that "this is the only specimen of a mammalian carpus in which the presence of five distinct carpal bones has been remarked." He concludes that here we have to "deal with five distal carpalia such as Gegenbaur has figured in Chelydra."

Bardeleben describes the same condition in a Hyperoodon and claims priority for his discovery.

It seems fair to conclude that the single bone, supporting as it does, inthe human subject, the fourth and fifth metacarpals, represents the fourth plus the fifth carpal, and is produced from these two elements by a process of fusion.

The assertion that a bone may disappear by some process of suppression, is at first sight supported by a reference to the type, where we find an element termed the centrale present, which is not apparent in the human and some other forms. The suppression of this element, in these forms, is stoutly maintained by some autherities, and the question is fully entered into in a later portion of this paper.

In the course of time a series of observations of anomalous conditions in the carpus of

the higher vertebrata, has led to the accumulation of a large number of statistics of the occurrence of supernumerary bones.

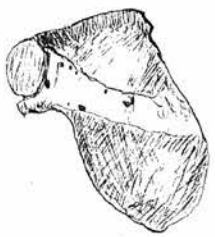
Wenzel Gruber and others have discussed these in the adult human carpus, whilst Thilenius has demonstrated their existence in the human foetus and in other mammalia.

The observations of Thilenius demand special notice, since they embrace the study of the occurrence of supernumerary elements in a large series of human embryoes. In these he seeks, by a study, of the histology, for an explanation of the genesis of the rarer elements. He finds that such elements do occur in the embryo, and that they are in their development precisely similar to the normal elements. The degree of development or retrogression of the element may be an index to the age of the embryo under examination,

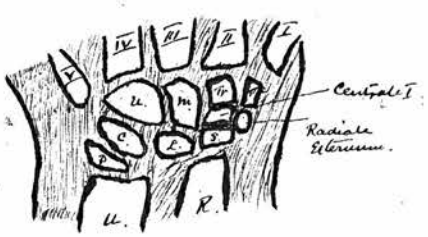
for it is found that the development or retrogression depends largely on age, or at least on the amount of development of the foetus. These stages or degrees of growth or development, can be divided according to him into three periods (1) that period which precedes the origin of cartilage cells, when the tissue, which is to develop into cartilage, consists merely of undifferentiated cells having no specific character.

(2) the period following the appearance of hyaline cartilage: this is divisible into two stages - in the first stage the arrangement of cells, which are to become tendons, ligaments, and muscles, is recognisable, but there is no trace of the formation of joint cavities; the second stage is characterised by the possession of joint cavities. (3) the period begins with the appearance of bloodvessels in relation to the cartilages,

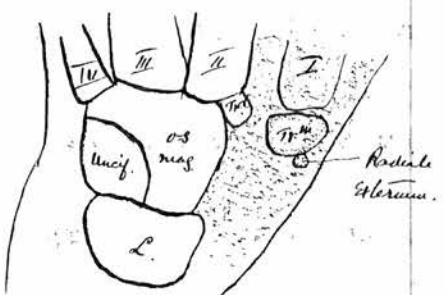
and embraces the ossification stage. Thilenius examined the hands of 118 human embryoes - 181 carpi, these belonged for the most part to his second stage of development. His conclusions are - that in the foetal as in the adult carpus, accessory elements are to be recognised, that their position is sometimes on the dorsum at others on the volar aspect, and that some are placed mesially, whilst others occur at one or other margin.



Scaphoid with Radiale Externum
(Pfitzner).



Carpus of Human Embryo showing
Radiale Externum and Centrale I.
(Thilenius)



Carpus of Human Embryo showing
Radiale Externum.

Radiale externum.

Although this element occurs with frequency among certain species of mammals, it is not found as a general rule in man. In the carpus of Elephas africanus it articulates with the scaphoid on its outer side. In the adult human carpus Pfitzner has been able to describe its occurrence on two occasions. From a consideration of the conditions of its occurrence among other mammalia, he surmised that in man it must be looked for only as a mere rudiment. Search amongst the soft parts around the tuberosity of the scaphoid, failed completely to throw any light upon its existence. Finally he came to the conclusion that, that portion of the scaphoid which articulates with the trapezium, must be looked upon as the fused radiale ext. This part of the navicular may be blunted off, or drawn

out into a process of considerable size. A more or less deep furrow may appear to mark it off from the surrounding portion of the bone. Pfitzner found this process existing as a separate ossicle in two cases. In both it articulated with the trapezium;and in both it showed a tendency to fuse with the scaphoid.

Between the navicular and the trapezium, and lying to the outer side of the centrale,Henke and Rehyer found in a human embryo,whose age was estimated to be about the sixth week,a cartilaginous mass which they looked upon as the precursor of a supernumerary ossicle.

Thilenius discovered a similar element in the hand of an embryo,which belonged to the first stage of his second developmental period. It was spherical in shape,but instead of being free on all

sides as in Henke and Rehyer's specimen, it was united with the proximal radial angle of the trapezium. The free surfaces were completely surrounded by a perichondrium, and the evidence of its earlier complete independence lay in the existence of a zone of closely packed nuclei, whose presence mark the limitation of a piece of cartilage in an early stage of development. Another, of Thilenius' specimens showed very similar conditions, but in this case the tissue of a process of the trapezium passed directly into the substance of the radiale externum, without the appearance of the zone of nuclei. In shape, size, and position, however, it corresponded to the specimen previously described. In none of these cases could any relationships be made out to the developing soft parts.

Scaphoid or Navicular.

The scaphoid articulates with the radius, trapezium, trapezoid, os magnum, and semilunar.

The distal and proximal articular areas are placed so close together, that, to adopt the description of Thane, "the dorsal free surface is reduced to a narrow grooved transverse strip, to which the posterior ligaments of the wrist are attached".

An examination of a number of navicular bones revealed the fact that in many cases the narrow grooved transverse strip may be replaced by a ridge. The dorsal area in one specimen measured 1cm. in breadth the average measurement for this surface being about 5mm.

In one case the scaphoid showed a minute ossicle lying upon its dorsal aspect, whose dimensions were as follows - 4mm. in greatest length

and 2mm. in greatest breadth. It lay in the angle between the scaphoid and the semilunar, articulated with the former by a ligamentous connection, and was covered in by the dorsal ligaments of the carpus. The manus in which this occurred belonged to the left side.

Another specimen, also belonging to the left limb, had the extremity of the tuberosity, which measured 8½mm. in length, and 4mm. in breadth, separated from the rest of the bone by a deep groove, on its distal aspect, whilst on the proximal side no indication of a separation was detected. Strong ligamentous fibres passed from it to the external aspect of the bone. This specimen is an example of the condition which has been named Naviculare imperfecte bipartitum.

One scaphoid possessed in addition to the normal dorsal groove a small flat surface which terminated in a minute tubercle on the dorsal area.

The line of junction of the tubercle with the main mass is distinctly visible, both from the dorsal and from the palmar aspects.

Many naviculars showed in addition to the rough dorsal groove for the attachment of ligaments- a smooth surface at the point at which the dorsal area joins the articular surface for the trapezium and the trapezoid.

Thirty-seven scaphoids were examined of these eighteen belonged to the left side, whilst the remaining nineteen were from right limbs.

Ten belonging to left limbs showed no dorsal surface, whilst eight possessed it: twelve from the right side had no dorsal surface, while the re - maining seven had it.

Pfitzner points out that the greater

number of the abnormalities of the scaphoid are dependent on the amount of fusion between the two chief portions— the radial and the ulnar halves. He finds that, that portion of the tuberosity, which he looks upon as the homologue of the radiale externum, failed to develop in twenty cases; it was scarcely marked in 60, in 83 weakly developed, well developed in 78, 46 had it strongly marked, 4 cases were doubtful: these are drawn from a total of 293 specimens examined.

Naviculare bipartitum.

Gruber described the occurrence of the navicular in two pieces in 1866, and Pfitzner gives the frequency of its occurrence as about 1%.

The two halves have been named naviculare radiale and naviculare ulnare respectively,

Naviculare Imperfecte Bipartitum (Pfitzner)

and this nomenclature indicates their position with reference to one another. The separation may not extend completely through the bone, in some cases, and the line of division may be indicated merely by a furrow - this condition is named naviculare imperfecte bipartitum an example of which is described under scaphoid.

A complete series of specimens has been investigated, showing all stages from the complete separation down to perfect fusion. This series points to the existence, at an early stage, of two portions in all cases, and these by their fusion produce the perfect scaphoid of the adult condition.

This view of the constitution of the navicular is supported by the observations of Rambaud and Renault, who found two ossification centres lying

close to one another in the middle of the scaphoid. The histological conditions observed by Thilenius all go to bear out this surmise. Still there appears to be some doubt as to whether the specimens observed might not have been those of the fusion of the centrale with the scaphoid, since this element was not traced out in those cases. However, some of the specimens of naviculare bipartitum which have been investigated in the adult carpus, have showed at the same time the presence of a centrale.

Semilunar or lunatum.

The semilunar bone articulates with the radius, scaphoid, cuneiform, os magnum, and unciform.

Lunatum bipartitum.

For the occurrence of this condition Pfitzner says that it is necessary that the lunatum can exist in radial and ulnar halves, or in dorsal and volar sections. The cases, which Gruber has described he looks upon as examples of the independent existence of the epilunatum or of the hypolunatum. He quotes a case of Turner's and says that this approaches more nearly the conditions laid down by himself for the occurrence of this abnormality, but even this case he is disposed to regard as a fracture of the navicular or an abortive example of the naviculare ulnare.

The specimens which have been described

as lunatum dorsale and lunatum volare he looks upon as due to an abortive formation of the epilunatum.

Lunatum tripartitum.

All the described cases are considered by Pfitzner to be the result of pathological lesions, or examples of the lunatum with independent existence of the epi- and hypolunatum.

Cuneiform, Triquetrum or Pyramidale.

The cuneiform articulates with the following bones - pisiform, semilunar and unciform.

Triquetrum bipartitum.

Two examples of this condition have been described by Thilenius. It consists in a deepening of the furrow, which separates the articular area for the pisiform from that for the unciform, so that the bone becomes divided into two parts of nearly equal dimensions. One of these portions is radial in position -triquetrum radiale; whilst the remaining part is ulnar - triquetrum ulnare.

Triangulare. —This element was noted by Pfitzner in one specimen in 1895, and has not been recorded by any other observer. It lay between the triquetrum and the head of the ulna, being limited on the radial aspect by the lunatum and the radius. Its position in the joint cleft is rather towards the volar aspect of the ulnar styloid. It has also been named Triquetrum Secundarium; and in all probability corresponds to the Os Camperi of the Gibbons.

Pisiform.

The pisiform articulates with one bone -the cuneiform, and is present in mah and all the primates. In the other primates it is elongated and more pronounced than it is in man.

Much controversy has taken place around the question as to whether it is to be regarded as a sesamoid bone, or as an actual element of the carpus.

An examination of its position reveals the fact that it lies on a plane anterior to the other carpal bones, and that it is embedded in the tendon of the flexor carpi ulnaris muscle.

Wiedersheim looks upon it as a sesamoid. Pfitzner defining a sesamoid bone as one which

cannot be brought into any other recognised category of skeletal elements.

Leboucq, who opposes the sesamoid theory of its origin, finds that it is developed at a stage prior to that of the formation of muscular tissue.

He has demonstrated its presence in a human foetus of 12mm., in which all the carpal elements were differentiated, and in which the formation of the muscles had not commenced. He concludes therefore that the relationship of the pisiform to the tendon is a secondary one, and acquired later than the development of the bone.

The position, which it has in the adult, articulating with the pyramidal, is also according to Leboucq, secondary in its development. He makes out

that the primary position is much more proximal, and intimately associated with the inferior extremity of the ulna. This relationship, he says is much more clearly seen in some of the lower animals, than it is in man, and from these facts he concludes that the pisiform is an actual element of the carpus.

On the other hand Gegenbaur at first thought that it was only an accessory to the carpus. However, in his paper on the skeleton of the limbs in Ichthyosaurus and Plesiosaurus, he in 1870 came to the conclusion, that the accessory bones placed at the ulnar margin of the limb ought to be considered as portions of a limb ray: and that the last vestiges of this ray were visible in the pisiform. This is practically Sebaucq's conclusion also, for he says that it is to be looked

upon as the homologue of a ray of the primitive fin greatly reduced in size. Later on Gegenbaur seems to have abandoned this view, and described the bone as embedded in the tendon of the flexor carpi ulnaris, so as to act as a sesamoid.

In 1885 Baur as a result of researches on the carpus and tarsus of Reptilia, came to a conclusion similar to that of Leboucq - viz. that it is the rudiment of a sixth ray.

Kohlbrugge points out that the pisiform in Hylobates has the appearance of a metacarpal: and from this fact is inclined to the belief that it is the rudiment of a sixth ray or finger. Concerning its relationship to the tendon of the flexor carpi ulnaris — he thinks that the muscle may be looked upon as a

flexor of the sixth finger.

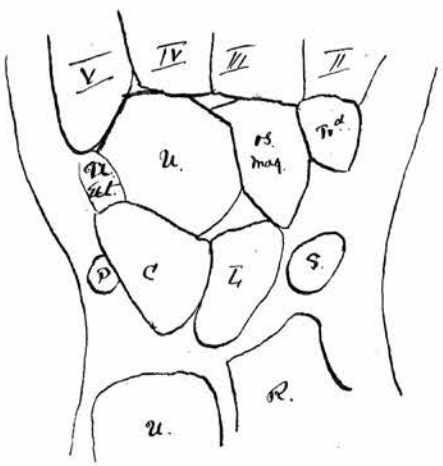
Bardeleben thinks that if relationship to muscles is a reliant guide, that then the pisiform is not an actual carpal, but must be looked upon as a metacarpal. He states that the true carpals do not give attachment to muscles, whilst the pisiform affords both origin and insertion to these structures: the flexor carpi ulnaris being inserted into it, and the abductor minimi digiti arising from it.

According to Bardeleben there are three posibilities which may be submitted concerning it——

1. It is an actual carpal.
2. It is a sesamoid.
3. It is the remains of a ray.

All the newest researches are against the second view; many are against the first; whilst he does not hesitate to support the third acceptation as the correct one.

Pisiform with Pisiforme Secundarium (Pfitzner).



Manus of Human Embryo showing
Ulnare & Centrale.

Pisiforme secundarium.

This element has been supposed to be analogous to the os Daubentonii, described by Kohlbrugge in the Gibbon. It lies in the jointcleft between the forearm and the carpus, slightly dorsal to the styloid process of the ulna.

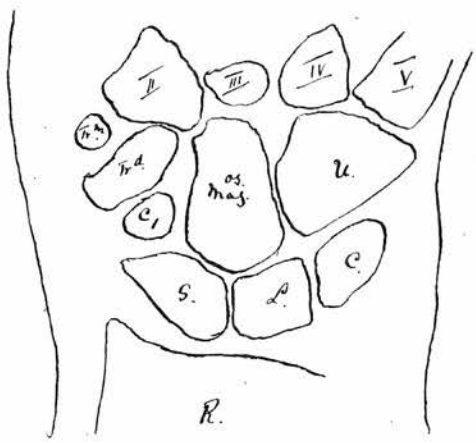
Ulnare externum.

Thilenius has described an ossicle which he found lying at the point where the distal angle of the cuneiform, meets that part of the unciform which is directed inwards and upwards towards the ulna. He regards it as comparable in position to the radiale externum on the outer margin of the carpus, and has therefore named it ulnare externum. It was found lying nearer the palmar than the dorsal aspect, and it

was separated from the base of the fifth metacarpal by embryonic connective tissue. It consisted of a spherical mass of hyaline cartilage. In the other hand of the same specimen, there was found a similar mass of cartilage cells in almost the same position, but pyramidal rather than spherical in shape. No relations to tendons, muscles or ligaments were to be made out, but it lay somewhat nearer the volar surface than the pisiform, which was lying in its original position.

Thilenius has found it in embryoes, which have reached the stage of joint cleft formation. From the histological appearances in some of the older specimens, he makes out, that the element fuses with the cuneiform. In the right hand of an embryo he showed the element with a quite independent existence, whilst in the left hand of the same foetus it was seen fused

with the cuneiform. This, according to Thilenius, may account for the condition called triquetrum bipartitum, in which the cuneiform is divided into a radial and an ulnar portion, but there is no record of the occurrence of such a division in the adult carpus.



Carpus of Human Embryo showing Centrale.

Os Centrale.

In 1876 Emil Rosenberg showed that the element known as the os centrale was present in a human embryo. Gruber had already described its occurrence in an adult carpus in 1869;prior to this date, according to Pfitzner,a number of more or less doubtful records are extant. For instance Eustachius in 1707, and Kulmus in 1722,may have described specimens in which it occurred. Pfitzner thinks that the description of the persistence of an os centrale,by Vincent,quoted by Leboucq,is not an example of this condition,but a typical one of that known as bipartite trapezoid.

Frequency of occurrence—— Statistics give very varied estimates of the frequency of the occurrence of this bone. The textbooks base their statements on the estimates of Gruber,who gives an average of decimal

four per cent. Pfitzner believes this to be far too low an estimate, basing this opinion on the ground that many of Gruber's specimens were prepared by inefficient methods, for the correct observation of its occurrence.

When present, in the adult carpus as an independent ossicle, it is said to be almost always recognisable, as soon as one has opened the intercarpal joint, from the dorsal aspect.

Stated in round numbers, from his experience Pfitzner gives the frequency as one %. In a first series of 200 hands he found 3 cases; in a second series of 382 hands — 3 cases; and in a third group of 197 no case occurred.

Personally, I macerated and examined a series of thirty-seven carpi, in the University Anat-

omical Department, each being disarticulated by severing the dorsal ligaments, and carefully scrutinised as recommended by Pfitzner, but without in any cases meeting with an indication of the existence of an independent ossicle in the situation named.

It is found between the proximal and the distal row, and although not a typical constituent of the human carpus, it does occur normally in other mammalia. Its most primitive position is said to persist in the Aye-aye (Cheiromys), where it occupies the middle of the carpus, in relation to all the other bones except the pisiform.

Flower states that it is absent in cheiroptera, carnivora, ungulates, cetacea, edentates, marsupials and monotremes. It is present in all the

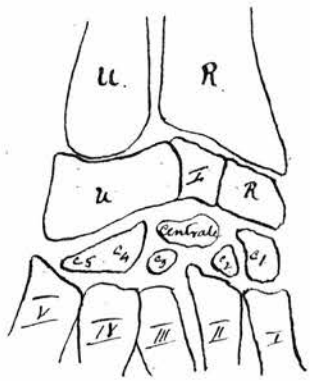
primates, asan independent bone, with the exception of man, gorilla, chimpanzee, and some of the lemurs. Amongst insectivora it is given as a constituent of the carpus in all except galeopithecus, potamogale, sorex, and chrysochloris. It is present in many genera of the rodentia, whilst it is absent in others.

Cuvier knew of the existence of this element in the mammalian carpus, and regarded it first of all as a derivative of the trapezoid, and later as a detached portion of the capitatum. On the other hand the position he ascribed to it in chelonia and other reptilia might be compared to that of the os intermedium.

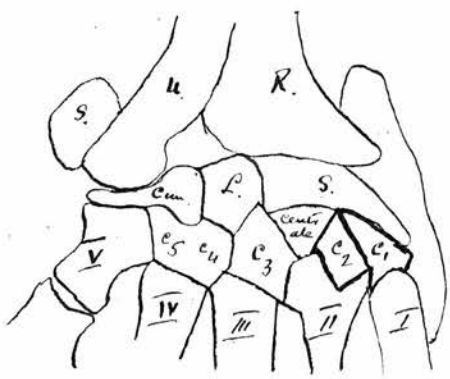
Meckel calls it a supernumerary bone, and considers it to be a result of fracture. He does not state definitely whether it is derived from the

trapezoid or from the scaphoid, but seems inclined to the belief that it is from the latter.

Owen mistakes the significance of this bone, for he looks upon it as a separated portion of the scaphoid. He regards what are now looked upon in the orang as the scaphoid and centrale, as subdivisions of the os scaphoides. Referring to the carpus of many reptilia, he says, "in many Chelonia as in Testudo elephantopus, Testudo graeca, in large individuals of Chelone mydas, the two inner or radial ossicles of the proximal carpal series are distinct as in the orang; they obviously therefore, represent the human scaphoid and the scaphoid only." He also points out that ossification begins "in that portion which is nearest the wrist in its middle part: that in some species this portion alone is ossified: that in other species the



Carpus from foetus of Lepus Cuniculus showing Centrale. (Gegenbaur)



Carpus of Talpa Europaea (Gegenbaur).

two portions coalesce and so form a single scaphoid bone as in man."

Gegenbaur recognises that the centrale present in some members of the mammalian group, is the same element he has described in the amphibia. In some of the rodentia, he notes that it has altered relations, from those which he regarded as typical in the Amphibia. In others again as in Lepus it remains surrounded by the entire carpus, and has maintained its original relationships. Among insectivora—the mole—it is present as a spherical ossicle with its base abutting on the scaphoid, whilst the rest of the bone lies between the capitatum and the trapezoid. He says that it might be counted with the second carpal row as Meckel counted it. The view enunciated by

Owen is criticised by Gegenbaur, who can see no grounds for its association with the scaphoid. It is to be regarded as a typical carpal element, because it forms a component of the foundation form of carpus, established by him for the four upper classes of vertebrata.

De Blainville, Vrolik, Gratiolet, Alix, Humphrey, Huxley, and Mivart agree with Owen in the view that it is a detached part of the scaphoid.

Thane in the section of Quain's Anatomy dealing with Osteology, says, "with reference to the centrale in the human subject, traces of it are often to be recognised in the adult scaphoid, and it may in rare cases be developed as a separate bone."

The presence of the centrale in the adult human carpus had been pointed out by Gruber in 1869. He examined the soft parts of the carpus in 812

cases and found only two centralia; while an examination of 420 naviculars revealed two more examples.

Henke and Rehyer in 1874, and Rosenberg in 1876, demonstrated that it was always present in the carpus of the embryo.

Leboucq says that it is always to be found during the first half of the second month of foetal life.

In the earliest stages observed by Rosenberg, it appeared as an approximately cylindrical body, with its long axis perpendicular to the surface of the carpus, and surrounded by the radiale, and carpalia 1, 2, and 3. It had no relation to the intermedium and showed no trace of an origin from two elements. Its structure was cartilage cells, with a deficiency of the matrix in which these cells were embedded.

In later stages its dorsal surface was made out to be broader than its palmar. In the latest stages of all Rosenberg thought that he saw the element disappearing It appeared to approach the radiale from which however it always remained marked off;then it gradually became converted into indifferent connective tissue,and disappeared from the palmar surface upwards. He combats the view that the scaphoid represents the navicular and the centrale.

In opposition to this view of Rosenberg,Henke and Rehyer held that the cartilage fused with the cartilage of the scaphoid. They based this opinion on an examination of a foetal carpus,at the beginning of the third month.

The view advocated by Rosenberg was the one which obtained general credence until Leboucq

proceeded to work through a series of embryoes, which belonged to the first three months of foetal life. He found that in an embryo of 12mm. all the parts of the carpus and metacarpus were fully differentiated. In this embryo the centrale was present as a relatively large nodule in relation to the other parts of the carpus. On the proximal aspect it was in relation with the radiale, and on the distal side with carpalia 1, 2, and 3. It had very little relation with the intermedium.

Leboucq's conclusions are as follows ——

1. The centrale is of constant occurrence in the human subject.
2. It appears in the first half of the second month of foetal life.
3. It commences to fuse with the radiale towards the end of that month.

4. Fusion begins progressively from the palm towards the dorsum;and from the radial border towards the ulnar.
5. Fusion is usually completed during the second half of the third month.
6. In the stage following the fusion histology reveals in a very evident manner the changes which have taken place.

The histological evidence referred to is a peculiar grouping of the cartilage cells at the distal extremity of the scaphoid,and the occurrence of a perichondrial like structure isolating that extremity.

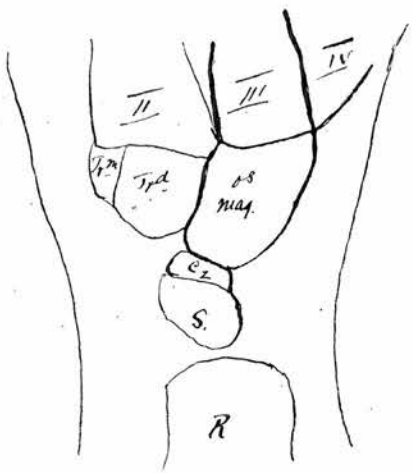
Although thus disposing of Rosenberg's view Leboucq himself describes a case in which,on both sides of the body,he was able to see the centrale in process of fusion with the capitatum.

Gruber has described a specimen of an

adult carpus where he regards the centrale as fused with the trapezoid.

Thilenius criticising the various theories, indicates that the amount of material at the disposal of any one of the investigators, has been so very limited, that all the variations of the ossicle can not have been made out, however he regards both Leboucq's and Rosenberg's theories as confirmed. According to him, the position of the bone in the human subject is invariably the same. In every case it lies between the navicular, capitatum, and trapezoid. On the other hand its shape and still more its dimensions are subject to great variation. It may be spherical, elliptical, or pyramidal with rounded angles. With respect to its size, it may reach from the dorsum of the hand to the volar aspect; in other cases it may only appear as

a few cartilage cells in a small number of sections. These variations in size may occur in embryoes at precisely similar stages of development. He does not believe the mere fact of these centralia being developed at different times, enough to account for this great disparity in size, and thinks that it rather indicates that the constancy of the element can undergo great variation. He produces a specimen showing that the bone may fuse simultaneously with two of its neighbours. Here, it is fused with the navicular, in the usual fashion, but in addition at its distal angle on the palmar aspect, it is ossified to the trapezoid. With Rosenberg, he holds that the ossicle may retrograde, and describes specimens where the histological conditions are indicative of retrogression and final disappearance. The space left by its disappearance being finally filled



Carpus of Human Embryo showing Centrale 2.
The same carpus showed also in other sections
Centrale 1. (Rabl-Rückhard).

up by a compensatory growth of the connective tissue.

He concluded, from an examination of seven hands, taken from four embryoes whose development corresponded to the stage in which the centrale is usually visible, that it may be entirely absent, for he failed to find any trace of it. In these cases the point corresponding to the usual position of the centrale was occupied by embryonic connective tissue.

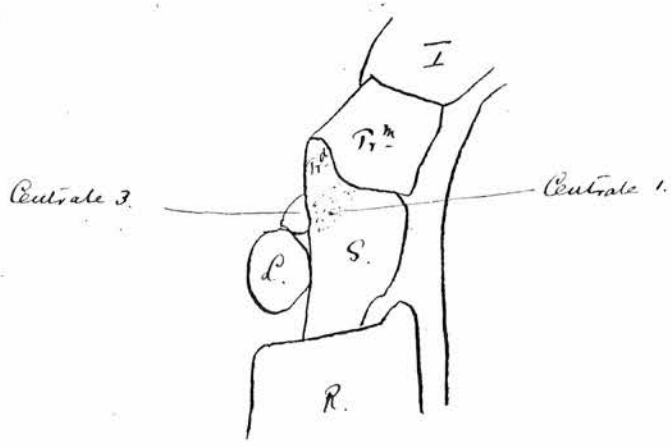
His conclusions are that the centrale rare in the carpus of the adult, belongs also in the embryonic carpus not to the constant elements, but to the inconstant: and that there are very considerable variations in its shape, dimensions, and amount of fusion with other elements, when it does occur.

Epilunatum or Centrale 2.

Besides the bone above described as the centrale, other elements have been found in the interspace between the two rows of the carpus. One of these has been named Centrale 2 by Thilenius, and Epilunatum by Pfitzner. It lies to the ulnar side, and to the dorsal aspect of centrale 1, and Thilenius found it in the hands of two embryoes, which had not reached the stage of joint cleft formation. Moreover, Bardeleben has described in a sixweeks foetus a line of separation cutting off the radial point of the lunatum. The small radial ossicle so cut off lay close to the centrale 1. Thilenius looks upon this as an identical ossicle to those described by himself and Pfitzner. In every one of the cases the centrale 1 was distinctly visible so that there was no mistake that an additional ossicle was present.

The two hands, which Thilenius found it in, belonged to the same subject, and it appeared as a wedge shaped piece of hyaline cartilage, the apex of which was directed towards the palm, between the navicular and the capitatum. The base lay towards the dorsal surface of the carpus, its ulnar end almost reached the lunatum, whilst radially it was separated from the centrale 1 by a zone of undifferentiated embryonic connective tissue. It was surrounded by a zone of perichondrium, and the portion of the hyaline cartilage immediately subjacent to this had a somewhat denser arrangement than that of ordinary cartilage. It was thus completely isolated from all surrounding bones, and there was no indication from the shape of either the lunatum or of the capitatum that it had been derived from them.

The fate of the cartilage, so laid down is probably to fuse with the lunatum, just as centrale 1



Carpus of human embryo showing centrale 3.

(Thilenius)

usually fuses with the navicular, should, however this not take place, then it may undergo an independent ossification and appear as a lunatum partitum.

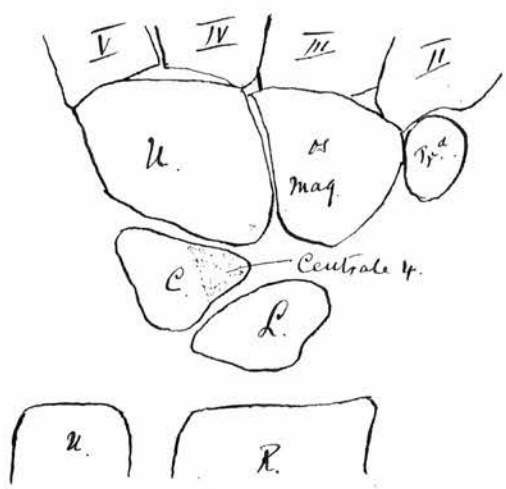
Hypolunatum or Centrale 3.

Gruber in the work on supernumerary ossicles, has described the occurrence of an ossicle lying on the palmar aspect of the semilunar, in the adult carpus. This ossicle may be fully isolated or may be bound in more or less intimate relationship with the semilunar.

Pfitzner has found it under similar conditions, and has named it the hypolunatum.

Thilenius called it centrale 3, and described it in course of development in a number of embryoes, which were at a stage in which there were no joint clefts formed, or these were merely in process of formation. It lay on the palmar aspect of the lunatum

and was spherical in shape. In the proximo-distal direction it lay between the navicular and the capitatum, partly lying on the latter bone. Its cartilaginous structure, when compared with that of the lunatum, clearly indicated that it had been deposited at a later stage than that element. It might be argued that this was merely the ossicle which has already been described as centrale 2 appearing on the palmar aspect instead of the dorsal, but the observations of Gruber controvert this, as he found simultaneously in the same subject the semilunar, and the centralia 2 and 3. That it is not merely a displaced centrale 1 is proved by the fact that in all the above embryoes described by Thilenius, that element was present in its normal position.



Carpus of Human Embryo showing centrale 4. (Pilcuicus).

Epipyramis or Centrale 4.

The elements above described as centralia are all lying between the two rows of carpals and to the radial side of the os magnum;but to the ulnar side of that element Pfitzner describes an additional element under the designation of epipyramis. To this bone Thilenius applies the name of centrale 4,and gives its position as on the dorsal aspect of the carpus, lying between the semilunar,cuneiform,os magnum and the unciform. He states that it has the shape of a four sided pyramid with rounded angles and edges,the base being directed towards the dorsal surface,and the apex towards the palm. He found it in six hands which were derived from three embryoes. In one of these it reached the size of the trapezoid,and was thus a larger

element than the centrale 1. The histology of all the specimens indicated that they were retrograding elements, for the usual perichondrium was awanting, and the subjacent more compact layer of cells was not differentiated, the element being embedded in embryonic connective tissue. Some of the specimens appeared to show that it acquired relationships to the ulnar dorsal angle of the semilunar, others that it fused with the radial angle of the cuneiform. The frequency of its occurrence is given as about 1 %.

Comparative Anatomy of the Centralia.

The centrale of the rodentia, which is laid down in the embryo, and which in certain genera persists in the adult as an isolated element, is, according to Thilenius, to be regarded as a centrale 1, as it

lies between the scaphoid, semilunar, and carpalia 2 and 3. He found a second element fully isolated in an embryo of Cavia cobaya, this he regarded from its situation, as a representative of centrale 4 of the human subject, for it lay to the dorsal aspect of the carpus, between the semilunar and the cuneiform on the one hand and the os magnum and unciform on the other.

Among the Insectivora, Bardeleben found in an embryo of Centetes madagascariensis two centralia, one of these evidently corresponded to centrale 1, and the other to centrale 4. Centralia are apparently absent in some genera, in addition to those mentioned by Flower, for Leboucq and Baur were unable to find them in Igel.

Leboucq traced the development of centrale 1 in Vespertilio muri~~a~~tus, and found that it

fused with the scapholunar.

Maisonneuve also described an additional centrale, whose position corresponded with that of centrale 4 in man.

Among Primates the centrale 1 is a constant and completely isolated element in the Orang: Kohlbrugge gives it as always present in Hylobates, but closely bound by ligamentous bands to the scaphoid.

In the Carnivora, the Centrale 1 is generally present during the development of the carpus, and in the later periods of foetal life it fuses with the scapholunar. According to Leboucq, in the stage immediately succeeding the differentiation of the cartilages, one sees on the radius, three elements quite distinct from one another, and each possessing its own relationships, these are the radiale, intermedium and

the centrale. At a stage a little more advanced, the fusion of these three elements begins; first the centrale with the radiale, by a cartilaginous tongue placed on the radial margin, and then the radiale and the intermedium begin to fuse at their upper borders. By the end of embryonic life the fusion is complete. During foetal life the centrale 1 has been demonstrated to exist in canidae, felidae, mustelidae, and ursidae.

A centrale 2 has been found by Pfitzner in the carpus of an adult house cat, and a similar element has been seen in other members of the group.

Leboucq and Weber both found that the Centrale 1 was present in many of the cetacea, but it was by no means a constant element. In the embryonic carpus of Monodon monoceros, Leboucq has found it in process of fusion with the intermedium and carpale 2. It has also been discovered fused with both carpale 1

and carpale 2 in the same specimen. The bone has been found free in very young foetuses of Beluga leucas, and in process of fusion with carpale 2 in older individuals of the same species. Kukenthal found two centralia in Beluga leucas; they were separated from one another by a distinct groove.

In the carpus of Globiocephalus melas a centrale has been found by some investigators, while others have failed to find it.

The conditions, which, according to Kukenthal, may exist in various species, are as follows—,—

1. One centrale.
2. Two centralia.
3. Centrale fused with radiale.
4. Three centralia.

From the position and relationships of these various elements, it is surmised that in the cetacea there may

be present centralia corresponding to centralia 1, 2, and 3 of the human subject.

A centrale has been found by Leboucq in embryoes of Didelphys and Halmaturus. It fuses with the radiale. Baur has confirmed these observations by researches on the carpus of Perameles and Didelphys.

Amongst the Monotremata Baur found a centrale present in Ornithorhyncus.

Trapezium or Multangulum Majus.

The trapezium articulates with four bones viz. scaphoid, trapezoid, and first and second metacarpals.

Para-trapezium.

This is a small element lying to the radial aspect of the trapezium. Cuyer recorded two cases of its occurrence in 1887: apart from this observation it has not been noticed.

Praetrapezium.

Gruber in 1875 described two cases, while since then Pfitzner has noted its occurrence no fewer than twelve times. It is therefore one of the commonest of the supernumerary elements, and its frequency is given as about 2 %. Thilenius has found it in the embryo, lying at the palmar aspect of the trapezium. The tendon of the flexor carpi radialis was made out dividing the trapezium into radial and ulnar halves: the radial piece had the element placed near its outer border. He found it in eleven carpi, which were obtained from seven foetuses. Some of the specimens showed it in process of fusion with the trapezium.

Trapezium Secundarium.

It is doubtful whether the condition which has been assumed to be trapezium secundarium has ever existed.

Trapezoid. or Multangulum Minus.

The trapezoid articulates with the scaphoid, trapezium, os magnum, and the second metacarpal.

Trapezoides Bipartitum.

It was first mentioned by Gruber in 1875, and is of extremely rare occurrence. Five cases in all have been described, and it has not been found up to the present time by Pfitzner. The trapezoid is divided into a dorsal and a palmar portion. The line of separation is described as running from the proximo-ulno-dorsal angle, parallel to the volar aspect. The palmar part is approximately cubical in shape, whilst the dorsal portion is characterised by the possession of surfaces which are markedly unequal in size.

Trapezoides Secundarium.

Only one specimen has been described and that by Pfitzner in 1895. By this term he means a

bone which he found lying in the angle between the trapezium, trapezoid, and second metacarpal. It appeared only on the dorsum of the carpus, and did not extend to the palmar aspect. Although Thilenius has not found it in the embryo, still he says that all its characters indicate a strong probability of its being discovered.

Os Magnum or Capitatum.

It articulates with the scaphoid, lunar, trapezoid, unciform, and second, third, and fourth metacarpals.

Capitatum Secundarium.

This was described in one case by Gruber in 1870. Its position was that of the portion of the os magnum which forms the dorsal distal angle on the ulnar aspect. As in Gruber's case it may be quite independent, or it may present varying degrees of fusion

with the os magnum. Pfitzner states that when the joint between the os magnum and the fourth metacarpal is well developed, that then the capitatum secundarium is well defined. Thilenius describes it as the antithesis of the Styloid, for it is found lying to the ulnar side of the os magnum, while the styloid lies upon the radial aspect. It lies distinctly towards the dorsum of the carpus, and according to him, not at all infrequently, traces may be made out of its fusion with the capitatum. A corresponding element has been found isolated in some other members of the mammalian group.

Unciform or Hamatum.

It articulates with five bones viz. os magnum, lunar, pyramidal, and the fourth and fifth metacarpals.

Os Hamuli Proprium.

The occurrence of this bone was noted

by Pfitzner in 1885, and he has seen it in 21 cases, giving a frequency of 4 % for its occurrence. He describes it as occurring quite independently of the unciform, in other instances articulating with it, in others separated from it by a considerable interval, yet again in others completely fused or partly synostosed. When developed to its greatest extent as an independent bone it articulates not only with the unciform, but also with the fifth metacarpal. In some instances it must be noted that the hook of the unciform is very weakly developed or in some cases it may be completely absent. In this connection it may be pointed out that Rambaud and Renault have described the unciform, as possessing two independent centres of ossification, and that one of these centres is for the hook of the unciform, and forms this exclusively.

Styloid.

Saltzmann described this element as long ago as 1725, and its presence has been frequently noted since then. Pfitzner mentions 77 specimens and gives the frequency of occurrence as 4 %. This is the bony process which is usually described as the styloid of the third metacarpal, and is in the great majority of instances completely fused with that metacarpal. In the specimens examined by me although none exhibited a complete separation, yet it seemed in some cases, that a very slight deepening of the line of junction, would have produced two separate and independent bones. It lies between the os magnum, trapezoid, and the second and third metacarpals. Even when completely detached it occupies the position of the styloid of the third metacarpal, appearing only on the dorsum, and never by any chance does it extend to the palmar aspect. Pfitzner describes three conditions any of which it may

be in 1. it may occur quite independently and then it articulates with the four contiguous bones. 2. it may be united with the third metacarpal, or the os magnum, or the trapezoid. (the nature of the union may be synostosis or it may be completely fused). 3. it may be fused with the third metacarpal, and at the same time be united with the os magnum, so that the three form one mass. Leboucq has studied it both in the adult and in foetal carpi. Thilenius describes it in some of his specimens as being of a somewhat low pyramidal shape, foursided with somewhat rounded angles. His series of sections show it in every degree of independence and of fusion with the third metacarpal. There is still another fate which may await this element, for he has found it fusing with the os magnum, leaving the third metacarpal without a styloid process. When it has fused with the os magnum, it gives it a process on its carpal surface, which is directed towards the radius. From specimens derived from the adult carpus it has

been known to fuse with the trapezoid. If the styloid exist as a separate element the tendon of the extensor carpi radialis brevior still runs over it, just as when it has become the styloid of the third metacarpal. Thilenius points out that this element is in existence before the development of muscle, tendon or ligament, and that therefore its genesis can in no way be attributed to these.

Metastyloid.

This is found only in a very rudimentary condition, appearing on the dorsum of the carpus, in the angle between the styloid, os magnum, and the trapezoid. It has been known since 1878, when it was described by Gruber, and has been met with, according to Pfitzner in some eight cases so that he states the frequency of occurrence as about 1 %.

Parastyloid.

This has only been found in one case

by Gruber, who in 1870 described a specimen in which it was present, and showed a central ossification centre. It appears, as a general rule, according to Pfitzner, to fuse with the second metacarpal. It occupies the angle between the styloid, trapezoid, second and third metacarpals. Thilenius has described it in his specimens as consisting of hyaline cartilage, of a pyramidal shape, the apex of the pyramid being directed down into the palm. It did not extend farther than the middle of the thickness of the carpus; and he has been able to trace its process of fusion with the second metacarpal.

Os Gruberi.

This element was noted by the anatomist whose name has been given to it, in his work of 1870; and since then Pfitzner has also recorded one example of its occurrence. It is a small bone, which lies completely hidden, at the volar aspect of the carpus, in the angle between the os magnum, unciform, third and fourth

M% metacarpals. It may be synostosed with the neighbouring bones or articulate with them.

Os Vesalianum.

Vesalius in 1555 described indications of a bone occurring at the ulnar margin of the hand, in the angle between the unciform and the fifth metacarpal. This according to Pfitzner is probably identical with one or other of the ossicles already described.

The literature of the human carpus, then contains references to some eighteen more ossicles, than are usually regarded as constituent elements of that carpus.

Summary of the condition of the carpus in other mammalia.

Primates—— Very few of the apes have been investigated in this relation; so it is not surprising that there are only a few statistics of the occurrence of

supernumerary elements amongst them. A pisiforme secundarium has been described in some species of Hylobates. In Hylobates syndactylous and also in Inuus ecaudatus, there is an intermedium antebrachii lying near the last mentioned element. The radiale externum is constant in the Orang and in the Chimpanzee, and it also occurs at times in the Gorilla, although not as a constant element. When present the radiale externum lies between the scaphoid and the trapezium and articulates with both. Some species of Hylobates possess a pretrapezium in addition to a radiale externum.

Cheiroptera—— In several species the radiale externum is a constant element, amd lies between the scaphoid and the trapezium. In some an independent styloid to the third metacarpal has been described. The occurrence of a capitatum secundarium has also been noted. In Vespertilio murinus a large element is found on the

palmar aspect of the carpus, extending from the middle of the base of the fifth metacarpal, with which it is united by a ligamentous band, to the third metacarpal. Leboucq looked upon this as a pisiform, but Thilenius considers that it is an Os Vesalianum.

Carnivora.

The radiale externum is well developed amongst the carnivora, and here it is that it exhibits its most characteristic form, namely that of a half spherical mass of considerable size lying between the scaphoid and the trapezium, and somewhat to the palmar aspect of these. Among the majority of species it is one of the constant series, and is readily found both in the adult and in the embryo. In the bears it does not exist as a separate element in the adult carpus, but forms the unusually large distal process, which characterises the scaphoid of these animals. The ulnare

externum has been described as occurring in a wolf:

whilst Procyon has been known to possess the pretrapezium

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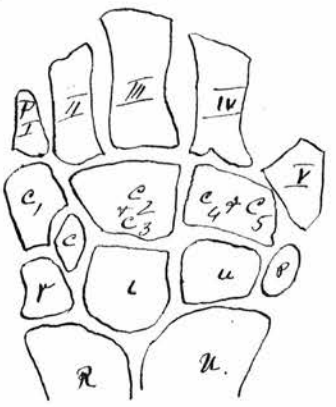


Flexor surface of the Manus of Mesoplodon bidens (Turner).

The radiale externum is present in the great majority of rodents, lying at the distal extremity of the scaphoid and reaching the first metacarpal. Owing to this position of the radiale externum, the trapezium is displaced from its normal situation, and lies much more to the ulnar side than in the human carpus. The independent styloid, and the capitatum secundarium have been noted in some species in the embryonic condition.

Cetacea.

Eight elements constitute the normal cetacean carpus, but in some cases a pisiform and a centrale are superadded. Not only the species, but also the individual members of the same species, seem to differ in the normal number of their carpal elements. The radiale externum is described as occurring in Tursiops tursio; Kukenthal has found it isolated in embryoes of Globiocephalus melas; and Leboucq has found it fused with the scaphoid in the same species. It is

said to occur frequently in Odontoceti. Elements have also been described as lying between the distal carpal row and the metacarpals.

Marsupials.

In the wombat, Pfitzner has found an intermedium antebrachii. The radiale externum has been seen by Baur, in a cartilaginous state, in the embryo of Phalangista cookii; whilst it has been found by Bardeleben in the adult carpi of many species. In these its most important relationship is not to the scaphoid but to the trapezium.

Monotremata.

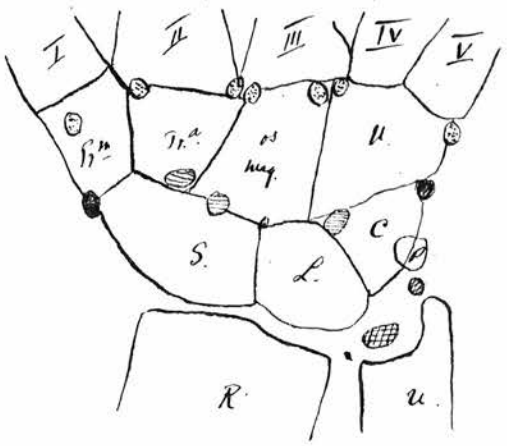
A radiale externum is described by Owen in the Echidna: where it articulates with the radio-intermedium, and with the radius. He also describes in the same species, elements which are comparable to the Os Gruberi and the Os Hamuli of the human subject.

The Primary Arrangement of the Carpal Bones.

The general statement made with regard to the arrangement of the bones of the carpus is, that they are arranged in two rows, a proximal and a distal. In man the proximal row contains the scaphoid, semilunar, cuneiform, and pisiform; the distal row consists of the trapezium, trapezoid, os magnum, and unciform. When a centrale is present it lies in the interspace between these two rows, so, in such a case the carpus could be considered as consisting of three rows, proximal, intermediate, and distal.

Albrecht describes the arrangement as in four rows, the bones being distributed as follows —

Proximal Row	Scaphoid, Lunatum, Cuneiform and Pisiform.
Second Row	Three centralia.
Third Row	Trapezium, Trapezoid, Os magnum, and unciform.



Scheme of the accessory ossicles (Thilenius)

ossicles of carpo-metacarpal row ⊙

" " central " ⊙

" " proximal " ●

" " antebrachial " ▨

Fourth Row Certain abnormal elements described by Gruber.

Thilenius has made out five rows in all when the position of the accessory elements is taken into consideration. His first row is an antibrachial one, lying between the radius and ulna, on the one hand, and the proximal row of the carpus, on the other. It consists of the two elements, which he has named, the intermedium antibrachii, and the ulnare antibrachii, or the pisiforme secundarii of Pfitzner. His next row is the proximal one, and its constituents are the scaphoid, semilunar, cuneiform, pisiform, and two accessory ossicles, the radiale externum, and the ulnare externum. The central row contains the centralia, which are numbered 1 - 4, from the radial to the ulnar side. It lies between the proximal and distal rows. The distal row has the trapezium, trapezoid, os magnum, and the unciform.

Hind fin of Baptanodon discus (Marsh).

The remaining accessory elements, which he has described, form the carpo-metacarpal row. It lies between the distal row of carpals, and the proximal extremities of the metacarpals. Thilenius, then gives, for the primary arrangement of the carpus, five rows, and he supports his argument by reference to the anterior extremity of Baptonodon, a fossil form, described by Marsh. In this the humerus is succeeded by three bones of similar size; these are the radius, the intermedium antibrachii, and the ulna; the next row consists of four bones which form the proximal row of the carpus. Following this, comes the central row, consisting of three or four elements, to be succeded by the distal row of six bones, and so on with the remaining rows, which are all composed of practically identical elements.

This view, that the occurrence of these

accessory elements indicates the disappearance of rows of carpals, from between the existing ones, is hardly compatible with the investigations of Leboucq, who believes that the distal row of carpals is derived from the posterior portions of the tissue, which forms the metacarpals. If this be the case it seems difficult to see how another row of elements can be interpolated between the distal row and the metacarpals. Leboucq speaking of the development of the manus in the dog, says that the metacarpals are probably differentiated before the proximal row of the carpus; the radius and ulna are to be seen cartilaginous in their middle portions, then a lacuna corresponding to their distal extremities, with the proximal row of carpals faintly indicated, being as yet in the stage of condensation of tissue prior to cartilage formation. On the contrary, the metacarpals already present cartilaginous formation

in their middle portions, whilst the distal carpals differentiate themselves in the proximal extremities of the metacarpals. He maintains that the first stages of human development are similar, and that the carpalia 1 - 4 are produced by the differentiation of the same skeletogenous pieces as the metacarpals.

Thilenius's theory is apparently untenable in the light of such a definite statement, and the question arises as to whether these accessory elements are actual carpal bones at all.

It might be argued that they were sesamoid bones — sesamoid bones according to Pfitzner being bones which cannot be brought into any recognised category of the bony portions of the skeleton.

Thilenius in support of the contention that the accesory elements are actual carpals, points

out, that they are developed from hyaline cartilage, which in no way differs from the hyaline cartilage of the eight normal carpals. They are developed at a period ~~of~~ /~~~~/ before that of the formation of joints, tendons, muscles or ligaments, so that they are in no way referable to these. Farther these abnormal elements are developed on both extremities in the same embryo.

Bardeleben states that the accessory elements appear after the development of the normal ones, for he finds very few accessory elements in the embryoes aged six to eight weeks, investigated by him. He says that Thilenius fails to substantiate his contention that these are actual carpals. He insists, that at least in the human subject, everything goes to show that they are to be regarded as rudimentary formations.

The Tarsus.

The bones of the mammalian tarsus are much less variable in their number, and arrangement, than are those of the carpus. Pfitzner divides the abnormalities, which may occur, into

1. The appearance of supernumerary elements.
2. Variations in form of the normal elements.
3. Differences in the mode of union between neighbouring bones.

The conditions in the tarsus do not appear to have been as well worked out as those in the carpus, but still an enormous quantity of literature presents itself for examination. Only some eight inconstant or accessory elements have been described, but these seem on the average to occur with greater frequency

than do the supernumerary ossicles of the carpus.

The occurrence of these elements in the human tarsus has been known from very early times, for example Vesalius mentioned some of them as long ago as 1555.

As in the examination of the carpus the method to be followed here is

1. A consideration and description of a number of the elements.
2. A consideration of the primary arrangement.

The usual number of bones in the human tarsus is ~~eight~~ seven; and the nomenclature applied to them is as follows——

Astragalus or talus.
Os calcis or calcaneum.
Scaphoid or navicular.
Internal or ento -cuneiform.
Middle or meso -cuneiform.
External or ecto -cuneiform.
Cuboid.

Astragalus.

The astragalus forms almost exclusively the tarsal portion of the ankle joint. The text-books, for descriptive purposes, divide it into a body, head, and neck. Its articular areas are for the tibia, fibula, calcaneum, and the scaphoid. His divides the bone into caput tali, corpus tali, collum tali, and the trochlea tali, which carries a facies superior, a facies malleolaris medialis, and a facies malleolaris lateralis. It also presents for examination two grooves, the sulcus tali, and the sulcus m. flexoris hallucis longi. He also distinguishes the following surfaces, facies calcanea articularis posterior, facies articularis calcanea media, facies articularis calcanea anterior, facies articularis navicularis, and two processes, processus lateralis and processus posterior. The articular facets are seven in number but great variability exists in this. In many cases a number of articular areas are recognisable

on the neck of the bone, on that area which is as a general rule non-articular. These have been described at great length by Professor Thomson of Oxford: they correspond with articular facets on the tibia.

I examined thirty-five astragali with reference to the occurrence of these facets upon the neck; twenty-five of these showed no articular areas, whilst they were present in the remaining ten. Three of them possessed both the inner and the outer facets; five had only the inner area; and two had only the outer facet.

Sulcus m. Flexoris Hallucis Longi.

An examination of the relative size of the tubercles bounding the groove for the tendon of the flexor longus hallucis gave the following results——

Fifty astragali were disarticulated and examined: of these twenty-five belonged to the right, and twenty-five

to the left limb. Four belonging to the left side had the inner tubercle more prominent than the outer; two from right limbs presented the same feature. In two right sided specimens the tubercles could hardly be said to exist, they were represented by mere ridges: one from the left side had a similar character. In all the others the outer tubercle was much the more prominent.

Articular Areas.

Of other facets which may be present Fawcett has described a surface which Pfitzner calls the facies articularis intermedia corporis tali. It lies between the superior surface and the outer lateral area, and is present in all specimens which are examined in a fresh condition, although it cannot be made out in macerated astragali. Pfitzner also describes a facies inferior accesoria tali, a surface which is separated from the tuberositas medialis by one limb of the sulcus

tali, whilst another limb of the same depression separates it from the inferior aspect of the neck. It articulates with a special facet upon the calcaneum, which lies in a groove between the body and the sustentaculum of the os calcis.

Facies medialis capitatis tali partita.—— Pfitzner says that two special facets can be made out between the facies anterior and the facies inferior, one of these is for articulation with the cuboid secundarium when it occurs, whilst the other is produced by the tibiale externum or by the terminal tendon of the tibialis posticus muscle.

According to Gruber when the os calcis presents the long single variety of sustentaculum tali, then the under surface of the head of the astragalus shows also a single long facet, which in about one fourth

of his cases, was subdivided into two areas by a transverse or oblique cartilage covered ridge. When the divided variety of sustentaculum tali occurs, two facets are present; these may be completely separated from one another by a furrow, named the anterior sulcus of the talus, or this furrow may not extend completely between them. In a number of cases the two areas are separated merely by a ridge, which may or may not be covered by cartilage. When a single short sustentaculum occurs there is only one facet present on the head of the ~~tibia~~ talus

Two hundred astragali examined by him gave the following results, there was present for articulation with the sustentaculum tali——

A single long facet in 99.

Single but separated into two neighbouring areas in 52.

Two facets in 32; the anterior sulcus being complete in 21; incomplete in 11.

A single facet in 14.

I examined forty - three astragali in this connection, and the surface for the sustentaculum tali was subdivided in all with the exception of four, where the area was continuous and undivided. Of these four two belonged to the right side and two to the left. None of them showed the articular area on the head for the cuboid, as sometimes occurs. Eight of the specimens had a well marked furrow separating the inner area for the sustentaculum tali from the outer. In each of these cases fibres could be traced backwards to the interosseous calcaneo-astragaloid ligament across the sustentaculum tali. They appeared to be interosseous fibres stretching between the groove subdividing the articular facet on the sustentaculum and the groove separating the corresponding areas on the head of the astragalus.

In each of the forty-three specimens it was apparent that there were facets upon the head,

one of these is for the navicular, one for the internal calcaneo-navicular ligament, and the remaining one for the calcaneum. The mode of separation of these three areas from one another varied in different examples. In specimens which had been kept for a considerable time and allowed to get dry, the lines of division were either apparently absent or could only be made out with difficulty. The majority of the fresh specimens possessed faintly marked ridges indicating the separation of the surfaces, but occasionally the ridges were replaced by grooves or furrows.

The Os Trigonum.

The astragalus is ossified from a single centre, which appears in the middle of the cartilaginous area representing that bone, during the seventh month of foetal life. Occasionally there is a second centre deposited in the posterior portion of the bone.

Should the portion of bone derived from the ossification of this second nucleus remain separate from that produced from the principal centre, then an os trigonum is the result.

The posterior surface of the astragalus is described by Bland Sutton as "little more than a ridge of bone traversed by a deep oblique groove, which receives the tendon of the flexor longus hallucis muscle. Externally this groove is limited by a prominent tubercle, which affords attachment to the posterior fasciculus of the external lateral ligament of the ankle."

Other authors describe the groove for the flexor longus hallucis, as bounded by two tubercles, one mesial the other lateral, of these the lateral is the larger. From the mesial tubercle ligamentous fibres pass to the posterior portion of the upper border of the inner surface of the os calcis, behind the sustent-

aculum tali. The fibres which form the sheath of the flexor longus hallucis tendon also find attachment to this tubercle. The lateral tubercle has been named the posterior process of the talus by Bardeleben, but Stieda objects to this designation as the term has been applied by Gruber (1864) to what is practically the entire posterior border of the astragalus.

Owen in communications to the London Zoological Society dated 1841 notes the occurrence of an os intermedium in marsupials. Rosenmuller 1804, Cloquet 1844, Schwegel 1859, Hyrtl 1860, Gruber 1864, Stieda 1869, Friedlowsky 1870, and Shepherd, Turner and Bardeleben in 1883, have all published communications on this subject.

Gruber states that the specimens described by Rosenmuller and Schwegel, were probably examples of sesamoid bones, and in sixteen cases he found comparable sesamoids.

Cloquet mentions the occurrence of an independent nodule of bone in the position of the lateral tubercle. He describes the trigonum as articulating with the calcaneum, fused with the talus, but separated from it by a furrow, and holds the opinion that it is a fragment which has been broken off and reunited.

In the discussions of the Anatomical Society of Paris Pigné expresses the opinion that it is an ossicle of new formation.

Hyrtl describes it as a trochlear process of the astragalus.

Gruber names the trigonum the talus secundarius, and says that it has been known to him since 1854. He mentions the occasional occurrence of a secondary ossification centre in the astragalus, the resulting bone from which can fuse or remain separate. It may unite with the talus by a synchondrosis or by

a true joint formation. He makes a special point of differentiating his talus secundarius from sesamoid bones which may occur anywhere in its immediate neighbourhood.

Luschka in his Human Anatomy states that the lateral process of the flexor longus hallucis groove, may be separated and develop as a separate bone. He does not mention any cases which have come under his own observation.

There have been numerous contributers to the literature of the os trigonum since 1883: and the Committee of Collective Investigation in 1890, state that the examination of 438 feet, showed the occurrence of this bone in twelve cases, or an average of 2.7%.

Pfitzner places the frequency of its occurrence at 8% : in the adult male as 7.5%, and in the female as 1.9%. Bardeleben gives 10% for its frequency.

Shepherd published a number of instances of its occurrence, and regarded these as examples of a peculiar fracture of the astragalus. He was unaware of the existence of any literature bearing upon this subject.

Turner described specimens and indicated that his view of the occurrence of this ossicle coincided with that of Gruber and Stieda.

Bardeleben described it as triangular, or half moon shaped. The frequency of its occurrence or of traces of its original separation from the talus varied in different parts of Germany. In Freiburg one third, in Jena one sixth, and in Berlin about one half of all astragali examined showed traces of the division.

Stieda described a number of cases, and stated that the ossicle should be regarded as possessing

three surfaces, namely an upper or posterior, an inferior, and an anterior.

In the fifty feet which I examined I noted the occurrence of a distinct os trigonum in two cases. One specimen was in a right foot, the other in a left. In the right astragalus the ligamentous relationships were intact, but these were partially destroyed in the preparation of the left bone. In both cases strong ligamentous fibres could be traced bridging over the groove for the flexor longus hallucis tendon. These fibres were attached to the os trigonum on the outer side and to the inner tubercle on the inner. The posterior calcaneo-astragaloid ligament was present in both specimens —passing from the os trigonum to the adjacent part of the os calcis. In the case of the specimen from the right foot, the posterior fasciculus of the external lateral ligament of the ankle joint was

still present, and in the same bone there were ligamentous fibres, binding the os trigonum to a concavity on the posterior aspect of the astragalus. These latter fibres had been destroyed in the example from the left foot, and the os trigonum exhibited a convex margin, which was not quite smooth, but exhibited near its centre two denticulate projections, which were lodged in depressions in the posterior margin of the astragalus.

The bone measured, in the case of the right os trigonum, in its broadest transverse diameter 2 c.m.: broadest anteroposterior 1.3cm. In the left the diameters were as follows —— greatest transverse 2.5cm.: greatest anteroposterior 1.4cm.

Following the nomenclature proposed by Stieda, for the surfaces, the upper or posterior surface in each case was rough and convex, it was also covered by fibrous tissue, which had to be removed, before the os trigonum was seen to be distinctly separable.

In both the inferior aspect was concave, and covered by articular cartilage. This cartilage was not continuous with that on the under surface of the astragalus, but was separated from it by a furrow filled with connective tissue, continuous with that binding the anterior area to the astragalus.

In the specimen from the right foot, the os trigonum did not include any portion of the groove for the flexor tendon, but was shut off from that area by a well marked ridge; whilst in the second specimen about one third of the flexor groove was formed by the os trigonum.

On the upper surface of the os calcis, there was in both, a backward prolongation of the cartilage of the posterior articular facet for the talus. This was convex in shape and adapted to the concavity on the under surface of the os trigonum.

In one astragalus from a left foot, the external tubercle was very large, whilst the internal was hardly indicated. The external tubercle extended for fully a centimetre over the adjacent portion of the os calcis. The extreme tip of this tubercle, when examined from the inferior aspect, was seen to be separated from the rest of the bone by a furrow on the articular cartilage. This separation could also be made out from the upper surface, but the furrow was not nearly so well marked as on the inferior aspect. The tip was freely movable on the rest of the tubercle.

Conditions in other mammals.

According to Bardeleben and Wiedersheim it is an element of constant occurrence amongst the five toed marsupials, and is in a more developed state than in the human subject. Pfitzner pictures it in a wombat, showing it with three well developed articular

surfaces by which it articulates with the tibia, fibula and astragalus. Bardeleben found it in almost all the species of marsupials examined by him, but it has not been found in other mammalia.

Pfitzner describes a number of conditions to which he applies the term spurious.

Talus Secundarius —— A name which Gruber had already applied to the trigone. It consists in the independent existence of the fibular angle of the talus, that part which lies near the tip of the external malleolus. He considers that it is the result of a traumatism, but at the same time thinks that it may be an indication of the existence of an accessory tarsal in this position.

Talus Accessorius —— In the same fashion this may be a fractured portion of the inner malleolus. It is not connected with the talus by any form of joint. Pfitzner only found it in one case.

Ossiculum Retinaculi —This is another of these spurious ossicles. It was described by Gruber who looked upon it as an ossification in the retinaculum peroneorum superius. Pfitzner says that it is an ununited fracture or pseudo-sesamoid.

Ossiculum in sinu tarsi —— This is another of the conditions described by Gruber, which Pfitzner looks upon as a sesamoid. It was in all probability a calcification such as one occasionally meets with in the bursae and synovial membranes of joints.

Os Calcis.

Gruber describes the os calcis as consisting of 1.a body which is the longer, upper and posterior portion of the bone, and corresponds with what is called the tuberosity in Quain. 2.the lower and shorter part — an anterior process. 3.a lateral process which supports the head of the astragalus.

Pfitzner describes 1.abody, on which ~~is~~ are placed the sustentaculum tali, the processus trochlearis, and the superior articular area. 2.posterior process with the medial and lateral tubercles and the tuberosity Achillis, with the flat trigonum Achillis. 3.anterior process, with the anterior articular area.

His recognises 1.a corpus calcanei- 2.a tuber calcanei with a processus medialis tuberis calcanei, and a processus lateralis tuberis calcanei. 3.sustentaculum tali. The surfaces which he names

are a facies articularis anterior, media, posterior, and cuboidea.

The surfaces described by Pfitzner are — facies articularis superior corporis calcanei, for the corpus tali; facies articularis superior sustentaculi for the collum tali; facies articularis superior processus anterioris calcanei for the caput tali; facies articularis anterior for the cuboid.

Sustentaculum Tali.

This process is described by Thane as carrying an articular area for the astragalus; this area being frequently divided into two, but the sustentaculum itself is frequently subdivided. Three fifths of Gruber's cases showed the ~~divided~~/undivided sustentaculum, whilst the remaining two fifths presented the divided variety. When it is subdivided (sustentaculum tali bipartitum) a furrow separates the two parts from

one another, so that one portion is on the anterior process, and the other on the body of the bone. The furrow has been named the sulcus calcanei anterior; it is transverse in direction and runs into the sulcus calcanei. Cruveilhier in his textbook published in 1851, had recognised and named the two divisions of the sustentaculum.

Anterior division of the sustentaculum. — This is the smaller part, and covers the whole or a portion of the anterior end of the calcaneum at its upper and mesial angle. Its termination is sometimes angular, sometimes rounded off. It presents two articular surfaces, — an upper, which articulates with the anterior facet on the under surface of the astragalus (caput tali); and a lower which passes without any limitation into the articular surface on the anterior extremity of the os calcis, and like that area articulates with the cuboid.

Posterior division of the sustentaculum. —This is always the larger of the two, and covers the mesial aspect of the bone. It is this portion which bears the groove for the flexor longus hallucis tendon on its under aspect.

Sustentaculum capitis tali simplex. —These are sustentacula where the sulcus calcanei anterior is absent. Gruber subdivides them into long and short simple sustentacula. The long variety constitutes about one half of all his cases, the short about one fifteenth. The short variety corresponds to the posterior part of the divided sustentaculum, or to the posterior portion of the long simple kind.

The long simple variety commences at the inner surface of the anterior half of the bone, and extends over the upper and inner angle. Three surfaces are described to it, superior, internal, and inferior.

The upper surface bears the articular facet for the head of the astragalus, and may be subdivided by a ridge into two areas. The inferior surface aids in the formation of the groove for the tendon of the flexor longus hallucis. The inner surface is rough and becomes a mere border, exceptionally it is grooved by the tendon of the tibialis posticus.

An examination of forty specimens of the calcaneum gave the following results———

19 belonged to the right side.

21 do. do. left side.

Long simple sustentaculum was present in 21.

do. do. do. with only one area in 12.

do. do. do. with two areas in 9.

Sustentaculum tali bipartitum in 19 cases.

Sulcus calcanei anterior showed an average of 8mm. in width and 5mm. in depth.

The posterior division was always the larger, the average length being about 16mm., whilst the breadth varied from 5mm. at the posterior to 10mm. at the anterior extremity. Its usual shape was oval, concave in the postero-external part, and convex in the anterior.

Anterior divisions gave an average of 1cm. for length and 5mm. for breadth. They were oval or almost circular in shape, with the upper surfaces weakly concave. In all of them the three described articular areas were present. The long axis of this division is directed forwards and outwards. The sulcus for the tendon of the tibialis posticus was present in one instance, which came from a left foot.

Sustentaculum tali bipartitum.

In a left os calcis —— The anterior division was concave, and projected forwards and inwards to terminate in a sharp point. In the posterior

division, the articular area only covered a portion of the sustentaculum. It projected beyond the posterior part of the sustentaculum in the form of a rounded tuberosity, which was rough and non-articular. This specimen showed the groove for the tibialis posticus tendon on the sustentaculum.

Right os calcis—— A minute ossicle passed in between the scaphoid and cuboid, and was attached by ligament to the anterior division of the sustentaculum.

Left os calcis——The sustentaculum was of the long simple variety and in place of the usual ridge between the sustentaculum and the facies cuboidea, there was a broad flat cartilage covered surface, which articulated with the navicular.

Right os calcis——The sustentaculum was

of the long simple variety, showing two areas, which were separated from one another by a strongly marked ridge.

Right os calcis——Sustentaculum of the long simple type. At its inner extremity there was a small ossicle, which measured 6mm. in its longest diameter, 2mm. at its broadest part, and 2mm. in depth.

Facies articularis cuboidea.

The anterior extremity is described in Quain as articulating "with the cuboid bone by a surface concave from above downwards and outwards, and convex in the opposite direction: and internal to this along the front of the sustentaculum tali, the internal calcaneo-navicular ligament is attached." Bland Sutton describes the surface as concave with the outer and superior angle somewhat prominent. Gruber says that it is sometimes triangular, sometimes irregularly quadril-

ateral. The portion of the articular area, which corresponds to the upper mesial angle of the anterior end of the calcaneum, and which forms the inferior articular area on the inferior aspect of the overhanging portion of the sustentaculum tali, is concave in the vertical and convex in the transverse direction. This area may be concave in the transverse direction, and this leads, if the adjacent under portion of the anterior articular area takes part in its formation, to a deep well marked groove on the mesial aspect of the bone under the overhanging sustentaculum. The cuboid usually articulates with this area, but the navicular may articulate occasionally with its mesial portion..

The mesial portion when well developed shows in some cases a pronounced angulus inferior, a well marked spine, or even a tuberosity. A weak groove, or a cartilage covered ridge may separate the mesial

portion from the remainder of the anterior articular area. This condition was met with in one specimen, an os calcis belonging to the left side, and presenting a broad cartilage covered sufface, well defined from the rest of the anterior area, for articulation, with the navicular.

Os sustentaculi proprium. ——This has been described by Pfitzner, who says that it consists of the upper and posterior angle of the sustentaculum. It is wedge-shaped, its upper surface completing the articular area of the sustentaculum, and articulating with the neck of the astragalus; whilst its under surface is fused with the sustentaculum. It is an element of very rare occurrence, for Pfitzner has only seen it twice during his investigations.

Processus trochlearis calcanei. ——The trochlear surface for the tendon of the peroneus longus, placed upon the

outer surface of the os calcis, consists of two grooves separated by a tubercle. The upper of these two grooves is for the tendon of the peroneus brevis, whilst the lower is for the peroneus longus tendon. The peroneal tubercle separating these two grooves is sometimes developed to an exceptionally great extent, and Gruber intimates that this development is independent of the age of the individual, for he found it most developed in a specimen from a foot in which the epiphysis of the os calcis had not yet fused with the main mass of the bone. Stieda found that it was present as a distinct tubercle in one third of all cases, and that it was as frequent in women as in men, indicating that it had no relationship to relative muscular development. Pfitzner found it absent or badly marked in about 60%, and present in 40% of his specimens. He says that it is absolutely constant in the cat, where in comparision with the os calcis it is much larger than it is in the human subject

In the same animal the peroneus longus tendon is relatively weaker, therefore he infers that the tubercle is independent of the development of the tendon. He believes that the explanation of its existence is to be looked for in the previous existence of an independent ossicle in this position. To support this view he points out that he has found it separate from the rest of the bone. The name which he suggests for it is calcaneus accessorius.

Calcaneus Secundarius. —Pfitzner gives an average of 2% for the occurrence of this condition. It is a small ossicle, lying in a concavity on the calcaneum, and possessing articular surfaces, one of which is for the caput tali, another articulates with the cuboid whilst the ossicle itself is intimately connected with the scaphoid by ligamentous fibres. Both Stieda and Gruber have described cases of its occurrence. Pfitzner

looks upon it as an actual tarsal. Kohlbrugge has described an inconstant element in some of the apes, which is regarded as comparable to the calcaneus secundarius, in man, it articulates with the navicular and the cuboid, but whether or not it articulates with the calcaneum also has not been determined.

Navicular or Scaphoid.

The scaphoid presents a facies articularis posterior, for the head of the astragalus; facies articularis anterior medialis, anterior media, anterior lateralis, for the first second and third cuneiforms. Besides the articular surfaces mentioned, in about 50% there is an articular area for the cuboid, and more rarely a facet for the tibiale externum, and one for the calcaneus secundarius, exist. When the variation known as cuneiforme bipartitum is present, there will also be

an extra facet -facies articularis intermedia- recognisable.

In Quain's Anatomy the outer end of the navicular is described as in some cases bearing a facet for the cuboid:Bland Sutton in Morris's Anatomy mentions that this surface is rough for ligaments,but that at the outerm, inferior angle,there is a facet,extremely variable in size,for the cuboid. Gruber describes it as rough and convex as a general rule,but in one twenty-fifth of his cases,he found it truncated or even concave. When the concave variety occurs,at the junction of the concave area and the dorsal surface,there is a pronounsed upper lateral angle. Three fourths of Gruber's cases showed an inferior lateral angle (angulus navicularis),which terminated in a blunt spine-spina navicularis.(egg shaped foundational form of Pfitzner). In a few specimens this spine was enlarged and resembled the tuberosity of the navicular,hence it

has been named the tuberositas navicularis minor.

The anterior aspect of the spine is very rough, and enlarges the rough plantar aspect of the bone. Its posterior surface is covered with cartilage, and aids in the formation of the facies articularis posterior, for the head of the astragalus.

One half of Gruber's cases carried a facet for the cuboid, in fourteen fifteenths the facet was single, and in one fifteenth it consisted of two areas. When it is single it is in almost direct continuity with the facet on the anterior aspect, for the ecto-cuneiform, being separated from this merely by a cartilage covered ridge. In fact many naviculars look as if they had four articular areas on the anterior aspect. Over two thirds of Gruber's cases showed this continuity between the outer area and the facet for the cuboid. The facet is usually placed at some

little distance from the spine, but may in some cases extend on to it, or even be confined to it. When there are two facets one is placed anteriorly and superiorly, whilst the other is below and behind and partly on the spine.

Should all trace of the tuberositas navicularis minor, be absent then another foundational type of navicular can be described viz. the quadrilateral. The presence of the tuberositas minor is really due to the fusiom of a cuboides secundarium; when the cuboides secundarium is absent the quadrilateral type of navicular is the result.

The inner surface of the scaphoid forms a large and prominent tuberosity —tuberositas navicularis major. It is associated with the insertion of the tendon of the tibialis posticus. Gray describes it as a rounded tubercular eminence. Gruber has noted

cases in which it was separate from the rest of the bone. He points out that the sesamoid of the tibialis posticus may be mistaken for this abnormality, especially if an adventitous bursa has formed between the sesamoid and the tuberosity. The separated tuberosity has been called a navicularis secundarium. The variations which actually exist in the tuberosity are dependent upon the tibiale externum. Gruber has proposed to call it the processus tuberositatis when it is developed to a great extent. Pfitzner says that a line of limitation marking off the processus from the rest of the tuberosity is recognisable in certain instances, and indicates the line of fusion of the tibiale externum with the tuberosity. This view is supported by the fact that the processus may carry a facet for articulation with the head of the astragalus.

Tibiale Externum. — This has been known for many years as the sesamoid of the tendon of the tibialis posticus.

It lies in the tendon of that muscle, just above its insertion into the tuberosity of the scaphoid. Pfitzner gives an average of 11 or 12% for its occurrence. In man it lies in relation to the astragalus and to the scaphoid. Its relation to the astragalus, is that it lies close to the caput tali, separated from this however in the majority of cases by the calcaneo-navicular ligament. It is usually fused with the scaphoid, but Luschka has described specimens in which actual joint surfaces were to be made out. Bardeleben says that it occurs as an independent cartilage up to the second month of foetal life in the human subject. Among rodents he describes it as placed upon the scaphoid and reaching the first cuneiform and the astragalus so as to articulate with these. It is a constant element in some carnivora, and insectivora. In the orang and several species of hylobates its occurrence has been noted.

First Cuneiform.

This bone articulates with its neighbours, by means of the following surfaces, facies articularis posterior for the navicular; facies articularis anterior for the first metatarsal; facies articularis lateralis posterior for the second cuneiform; and facies articularis lateralis anterior for the second metatarsal. It also presents, on its inner surface a groove, which runs obliquely to end in an oval facet into which the greater portion of the tibialis anticus tendon is inserted. The groove has been named the sulcus m. tibialis antici. There is in some cases a facies articularis anterior accessoria, lying between the facies articularis lateralis anterior and the facies articularis anterior, it is for the intermetatarseum.

Cuneiforme 1 Bipartitum.

The frequency of its occurrence according to Pfitzner is about ½%. In this condition the

first cuneiform is divided into two portions, by a horizontal line of separation, so that the bone consists of a dorsal and a plantar section. Various degrees of fusion, and of separation, between the two parts, have been met with. It is believed to indicate a previous existence of the first cuneiform in two portions. Pfitzner has described a small ossicle, under the name of precuneiform, lying alongside the first cuneiform, in a number of the carnivora and the rodentia, this he believes to be comparable to the condition of cuneiforme bipartitum, the dorsal section being the usual cuneiform, whilst the plantar section is the precuneiform.

Second Cuneiform.

It articulates with the external and internal cuneiform bones, the scaphoid and the second metatarsal. Any variations or modifications which are recorded are merely due to greater or lesser develop-

ment in size.

Third Cuneiform.

It articulates with the second, third, and fourth metatarsals, and with the middle cuneiform, cuboid and scaphoid bones. Pfitzner names the articular areas as follows——facies articularis posterior for the scaphoid; facies articularis anterior for the third metatarsal; facies articularis medialis posterior for the second cuneiform; facies articularis medialis anterior for the second metatarsal; facies articularis lateralis posterior for the cuboid. Exceptionally two other surfaces may occur viz. facies articularis lateralis anterior for the fourth metatarsal, and facies articularis anterior inferior, which is due to a projection of the facies articularis anterior on to the inferior aspect of the bone.

Processus Uncinatus of the Third Cuneiform.

Pfitzner has found in the human subject

a process to which he applies the above term, and which is analogous to the process which springs from the plantar aspect of the third cuneiform in certain carnivora, particularly in the felidae. It is especially well developed in the common cat, where it springs from the proximal portion of the third cuneiform on its plantar aspect, and lies upon the base of the third metatarsal, without however any joint being formed between them. The cuneiform bone and the third metatarsal are described as forming a groove in which the terminal tendon of the peroneus longus plays. In one specimen of the cat, Pfitzner found this process articulating by means of a joint surface with an actual os unci. In the canidae he found in place of the process only an anteriorly directed tubercle, which he looks upon as a retrogression of the fused process and os unci. In the one human specimen, in which he found the process,

it is much less well developed than in the cat. Although only found in one individual as a definite process, yet in many there is a distinct swelling on the under aspect of the third cuneiform.

Cuboid.

The cuboid is described in Quain as a bone, which deviates rather from the cubical form, and approaches the pyramidal, by the sloping of four of its surfaces, towards the short rounded external border. Its articular surfaces are — facies articularis posterior for the calcaneum; facies articularis medialis anterior for the cuneiform 111; facies articularis anterior medialis for the fourth metatarsal; and the facies articularis anterior lateralis for the fifth metatarsal. His names two special points in connection with the inferior surface namely the sulcus m. peronei and the tuberositas ossis cuboidei. The latter term is applied to a thick oblique ridge on the inferior aspect of the bone, whose outer end bears a smooth facet for the sesamoid of the peroneus longus tendon. This ~~sulcus~~ ridge bounds the sulcus m. peronei posteriorly.

Gruber describes the under aspect of

the cuboid as possessing two rough, rounded, comblike, projections, a furrow and a fossa. The anterior projection he names the anterior tuberosity, and the posterior the posterior tuberosity. The two projections may meet at the inner border in a tuberositas cuboidei communis. The fossa enclosed by the projections is named the fovea or sinus cuboidei. The peroneus longus tendon lies in the furrow in front of the anterior tuberosity. A process of bone may be present at the posterior extremity of the posterior tuberosity, at the angle where the hinder, under and medial surfaces come into contact. This process is directed backwards and inwards and was named the calcaneal process of the cuboid by Cruveilhier, and the processus cuboidei by Gruber.

The inner or medial aspect of the cuboid presents near its middle, and reaching its upper margin, the articular area for the ectocuneiform, behind this there is in many instances an articular surface for the

navicular. Gruber found this area in more than half of the specimens examined by him.

Cuboides Bipartitum. —— Blandin in his textbook published in 1834, says that the cuboid bone in some cases is divided into two portions. This would be a proof that the cuboid represented tarsalia 4 & 5. Pfitzner says that no other observer has recorded this condition, and is disposed to doubt its existence.

Os Vesalianum. ——This is a very rare bone, for its occurrence has only been observed in some four cases. It lies in the angle between the cuboid and fifth metatarsal, at the fibular margin of the foot, and articulates with both of them. Its occurrence has been noted at a very early stage of development, where it was a cartilaginous nodule, with a joint between it and the neighbouring cartilages. Its fate is to fuse with the fifth metatarsal, of which it forms the tuberosity. Pfitzner

has found traces of its independent existence in several species of mammals.

Intermetatarseum. ——This element appears to be of comparatively common occurrence;Gruber giving it an average of 7.5%,and Pfitzner 10%. It is a small bone placed on the dorsal aspect of the proximal end of the first interosseous space. Three surfaces have been described to it,a free dorsal,and two lateral,one of which is directed towards the first,and the other to the second metatarsal. Observations have been recorded, noting its articulation with the first and second metatarsals,and with the first cuneiform. Apparently it may articulate with any one of these or with them all. In all probability it ultimately fuses with one of these bones,so that it may appear as a process of the first cuneiform,or of the first,or of the second,metatarsal.

Peroneal Sesamoid.

According to 'Quain'there is a sesamoid fibro-cartilage or sometimes a bone found in that part of the terminal tendon of the peroneus longus, which plays over the tuberosity of the cuboid. Pfitzner's observations give a frequency of 8 or 9% for its occurrence; and it is more frequent in the male than in the female as 7.9% to 6.2%. No homologue has been found for it among other mammalia, if one excepts some of the lower primates, in whom it is a constant element and developed to a greater extent than in the human subject. When it is present it articulates with the postero-lateral end of the oblique eminence of the cuboid, the sesamoid being provided with a surface which glides over a corresponding area on the cuboid. In its most highly developed form, Pfitzner describes it as having an internal surface directed to the cuboid, a distal surface directed to the fifth metatarsal, and a dorsal and plantar surface which meet at the lateral angle.

In the other primates, amongst whom it occurs, there is often a well developed joint between it and the cuboid, the joint surfaces being covered by hyaline cartilage. In man, however, evem when the cuboid is still cartilaginous, the sesamoid is covered by a layer of connective tissue. Pfitzner points out that the sesamoid does not lie in the sulcus cuboidei as described in many of the textbooks, but lies upon the eminentia obliqua, the sulcus being occupied by the tendon with some fat, and loose connective tissue.

The Primary Arrangement of the Tarsal Bones.

The bones which constitute the tarsus may, according to the textbooks, be regarded as forming two columns, an inner and an outer. The inner column has the astragalus, scaphoid, and three cuneiforms for its constituents; whilst the outer is formed by the os calcis and cuboid.

In the light of more recent researches, Pfitzner looks upon the ossiculum trochlae, tibiale externum, and the plantar portion of the first cuneiform, as forming the tibial column in man: whilst in some mammalia the precuneiform is an additional element in this column. The fibular column he regards as formed by the calcaneus accessorius, the peroneal sesamoid, and the os vesalianum in addition to those usually mentioned in this group:

whilst added to these one has in some of the mammalia the calx calcanei. The intermetatarseum he is disposed to regard as evidence of the prior existence of a ray, which has disappeared from between the first and second rays.

The arrangement of the bones into proximal and distal rows, places the astragalus, os calcis, and scaphoid in the proximal, whilst the three cuneiforms and the cuboid are given to the distal row.

According to another description the bones are arranged in a proximal and a distal row, but the scaphoid instead of belonging to the proximal row is an element interposed between the two rows.

Pfitzner proposes from his extensive investigations, that there should be six rows recognised and gives their constitution as follows -

1 Preproximal, tarso-crural, or crural row.

Os trigonum.

2 Proximal row.

Talus, os sustentaculi, calcaneus, calcaneus accessorius.

3 Central or intertarsal row.

Tibiale externum, naviculare, cuboides secundarium, calcaneus secundarius, and peroneal sesamoid.

4 Distal row.

Cuneiforme 1 plantar, cuneiforme ~~1~~ 1 dorsal, cuneiforme 2, cuneiforme 3, cuboid.

5 Ultimate or tarso-metatarsal row.

Pars peronea metatarsale 1, os unci, os vesalianum.

6 Metatarsal row.

Metatarsale 1, intermetatarsale, and metatarsalia 2 - 5.

Tables of Homologies.

Gegenbaur

Carpus	Tarsus
Scaphoid and Lunatum.	Astragalus
Triquetrum	Calcaneus.
Centrale	Naviculare.
Carpalia	Tarsalia.

He did not regard the Pisiform as one of the ordinary constituents of the carpus, and therefore did not look for a homologue in the tarsus.

A later scheme of Gegenbaur's is as follows-

Carpus	Tarsus
Scaphoid without tuberosity.	Anterior or tib--ial part of the Astragalus.
Lunatum	Fibular or post-erior part of Astragalus.
Triquetrum	Calcaneus without tuberosity.
Pisiform	Tuberositas calc.
Scaphoid tuberosity	Navicular.

Earlier observers than Gegenbaur, as for example Owen, had wished to regard the pisiform as the homologue of the os calcis or of its tuberosity.

Bardeleben.

Carpus	Tarsus
Scaphoid regarded as radiale and centrale	Cartilage of the tuber. navicular.
	Rest of navicular.
Lunatum	Trigonum.
Triquetrum	Talus
Pisiform	Calcaneus.

Bardeleben another table

Carpus	Tarsus
Tuberosity of navicular (naviculare rad.)	Tuberosity of the navicular. (naviculare med. or tibiale).
Navicular without tuber. and centrale.	Head of Talus.
Lunatum radiale	Body of Talus.
Lunatum ulnare	Trigonum.
Triquetrum radiale	Anterior part of the os calcis.
Triquetrum ulnare	Posterior part of os calcis. excl. epiphysis
Pisiform	Epiphysis of os calcis
Centrale	Lateral part of the navicular.
Head of os magnum	Proximal part of the third cuneiform.
Proximal part of unciform.	Cuboid prox. part.
Tuberosity of trapezium	Plantar section of first cuneiform.
Trapezium excl. tuberosity	Dorsal section of first cuneiform.
Trapezoid	Second cuneiform.
Distal part of os magnum	Third cuneiform excl. proximal part.
Distal part of unciform	Anterior part of the cuboid.
Hook of the unciform.	?.

The above scheme is modified from a table given by Bardeleben. The tuberosity of the navicular of the Car--pus he regards as a portion of the prepollex, the rem--ainder of this digit being represented by the tuber-osity of the trapezium. These two portions of bone are looked upon as the homologue of the first finger in

the Urodela. In the same way the tuberosity of the navicular in the foot, together with the plantar section of the entocuneiform represent the prehallux.

The navicular of the carpus represents the naviculare radiale in its tuberosity, the radiale or scaphoid pro--per and the centrale. The head of the astragalus is the tibiale, and the homologue of this is the radiale represented in the human carpus by the scaphoid minus its tuberosity and the part derived from the centrale.

The radiale and tibiale are respectively the firstbones of the carpus and tarsus in the proximal row.

Semilunar in its radial part is the second bone of the proximal row of the carpus or intermedium 1 and finds its homologue in the body of the astragalus, which is the first bone in the proximal row of the tarsus, or intermedium 1 of tarsus. Semilunar in its ulnar section is the third bone of the proximal row; it is the inter--medium 2 , and its homologue is the third bone of the proximal row in the tarsus, the intermedium 2 or the Trigonum. The fourth bone in the proximal row of the carpus is the radial half of the cuneiform or ulnare, its homologue is the fourth bone of the proximal row in

the tarsus, the anterior part of the calcaneum or the fibulare. The fifth carpal of the proximal row is the ulnar portion of the cuneiform, its homologue is the fifth tarsal of the proximal row, or the hinder part of the calcaneum excluding its tuberosity.

The pisiform forms the sixth carpal of the proximal series, its homologue being the epiphysis of the calcaneum or the sixth tarsal of the proximal row.

The centrale, which as a general rule is fused with the scaphoid, is the centrale 1 of the carpus, its homologue being the centrale 1 of the tarsus, or the lateral portion of the navicular. The carpal centrale 2 or triangulare carpi, is the head of the os magnum: its homologue is the centrale 2 of the tarsus, triangulare tarsi or the proximal part of the ectocuneiform. Centrale 3 of the carpus is the proximal part of the unciform, and its tarsal homologue is found in the centrale 3 or the proximal division of the cuboid.

The first carpal of the distal row is the trapezium minus its tuberosity, or carpale 1, its homologue is the

tarsale 1, or dorsal part of the entocuneiform. Carpale 2 is the trapezoid, with its homologue in tarsale 2 or the mesocuneiform. Carpale 3 is the distal portion of the os magnum, whilst the homologue is tarsale 3 or the ectocuneiform, exclusive of its proximal section. The distal part of the unciform represents carpalia 4 and 5, the homologues of which are tarsalia 4 and 5 or the anterior part of the cuboid. Carpale 6 is the hook of the unciform, and its homologue is tarsale 6, but he has not made out what represents this. He has omitted from the table any mention of the homologue of the proximal part of the ecto cuneiform.

Baur looks upon the tibiale as a sesamoid bone, and con-siders the astragalus as an intermedium, the calcaneus as the fibulare, and the navicular (which is the centr-ale plus the tibiale) as a centrale. He draws up the following scheme-

Carpus		Tarsus
Scaphoid	Rad. Tib.	Tibial sesamoid bone, part of the navicular.
Lunatum	Centrale1	Distal part of the talus.
Triquetrum	Intermedium	Prox. part of talus

Carpus		Tarsus
Pisiform	Ulnare, Fibulare	Calcaneus.
Radial sesamoid	Carp. 1, Tars. 1	Tarsale.
Trapezium	Carp. 2, Tars. 2	Cuneiform 1&
Trapezoid	Carp. 3, Tars. 3	Cuneiform 2
Magnum	Carp. 4, Tars. 4	Cuneiform 3.
Hamatum	Carp. 5, Tars. 5	Cuboid.

Albrecht gives the following table for the homologies of the proximal row.

Carpus	Tarsus
Scaphoid (radiale)	Navicular (tib.)
Lunatum -intermedium-	Astragalus.
Triquetrum - do. 2-	Trigonum.
Pisiforme (ulnare)	Calcaneus (fib.)&.

Final table given by Bardeleben.

Carpus		Tarsus
Scaphoid	Radiale	Naviculare tib.
Centrale	Centrale 1	Naviculare fib.
Lunatum	Intermedium	Astragalus
Triquetrum	Ulnare	Trigonum.
Pisiform	Postminimus	Calcaneus.
Trapezium	Carp.-Tars. 1	Entocuneiform.
Trapezoid	do. do. 2	Mesocuneiform.
Capitatum	do. do. 3	Ectocuneiform.
	centrale 2	(triangulare).
Hamatum	Carp.- Tars. 4 & 5	Cuboid.

Eisler draws up the following table-

Carpus		Tarsus
Naviculare	= Radiale	:Fib. = Calcaneus
	Centrale prox.	:Centr. prox.
Lunatum	= Intermedium	:Intermedium-Talus
Triquetrum	= Ulnare	:Tibiale = tibiale of rodents. (tuberosity of the nav.)

Carpus	Tarsus
Os trigonum carpi	Os trigonum tarsi
Centrale (head of capitatum) = centrale distale	Centrale distale = Naviculare tarsi
Body of capitatum = carpale 3	Tarsale 1 = ento--cuneiform.
Trapezoides = carpale 2	Tarsale 2 = meso--cuneiform.
Trapezium = carpale 1	Tarsale 3 = ecto--cuneiform.
Hamatum = carpalia 4 & 5	Tarsalia 0 & 00 = (tibial sesamoid of mammals) ??
Radial sesamoid (prepollex) = carpale 0	Tarsale 4 = cub--oides tibial.
Carpale 00	Tarsale 5 = cub--oides fibular.

Theories concerning the homologue of the Pisiform.

Owen homologises the pisiform with the tuber -osity of the os calcis, and says that "the prominent part of the calcaneum, obviously repeats the prominent pisiforme".

Vicq D'Azyr makes it find its homologue in the calcaneum.

Huxley gives the cuneiform and pisiform as equal to the calcaneum.

Gegenbaur says that the bone is not a typical carpal, and that therefore it is not strange that one cannot find a homologue for it in the tarsus.

In 1883 Bardeleben gives the homologue as the pisiform, the remains of a sixth ray, corresponding to the tuberosity of the calcaneum, which is identical with the conclusion of Owen in 1848. In 1885 he homologises it with the calcaneum, the same view as Vicq DXAzyr pro -mulgated in 1774. In 1886 he considers that it is a sixth carpal in the proximal row, and therefore the hom -ologue of a tarsal in the same position-a sixth tarsal from this he draws the inference that it is the homo- -logue of the epiphysis of the os calcis. "In the young

bear, and also in some other animals, the enlarged pisi-
-formhas an epiphysis exactly similar to that on the
os calcis, and this according to Allen Thomson tends to
refute the view that the pisiform corresponds to the
calcaneal epiphysis". In 1894 Bardeleben makes it out
to be a postminimus, and homologous with the calcaneum.
He gave up the view that it was homologous with the
distal portion of the calcaneum only, after comprehens-
ive anatomical and embryological researches, on the con
-dition of the pisiform, in mammals and the lower vert-
-ebrates.

Baur thinks that it is the homologue of the
calcaneum. Later he expresses the belief, that it re-
presents a sixth metacarpal, and that therefore it is the
homologue of a sixth metatarsal.

Albrecht homologises it with the calcaneum
recognising it as an ulnare, and the calcaneum as a fib
-ulare.

Homology of the Astragalus.

Gegenbaur makes the astragalus consist of tibiale and intermedium, and compares it with the navicular and the lunatum of the carpus. He makes no statement as to the correspondence of the primitive parts of the bone with these.

Wiedersheim says "in the proximal tarsal row three bones originally lie, viz. tibiale, intermedium, (os trigonum), and fibulare, only in some cases e.g. all five toed marsupials, do they remain separate throughout life. As a rule two of them fuse to form one mass, that is to say the tibiale and the intermedium. The bone formed by the fusion of these two is then termed the talus or astragalus". He says that this also holds good for the human subject, where during the sixth week of foetal life, the intermedium is laid down

as a special cartilage. As a variation the intermedium may remain separate in the adult.

Bardeleben examined some fifty examples de - rived from thirty species of marsupials, and found an isolated bone lying between the distal ends of the tibia and fibula, on the one hand, and the astragalus on the other. He describes this bone as varying greatly in size, both relatively and absolutely. In the Wombat it measured a centimetre, in other species less than a millimetre. Ligamentous bands bring it into relation with the neighbouring bones, and are the homologue of the cartilago triquetra of the carpus. In the Mono - tremata the talus is incompletely divided into two parts. A similar condition subsists in the Edentata. The condition of these bones resembles that of the hum- an subject during the second month of foetal life. There is distinct evidence of an earlier separation in elephas, hippotamus, and tapir. In the human embryo at

the second month, the os trigonum is already laid down as an independent cartilage. At this period whilst still independent, the cartilage is conspicuously larger than the talus (tibiale), or the os calcis (fibulare). Its destiny is to fuse with the talus at a later time.

Bardeleben's conclusions are as follows -

1 In the lower mammals the intermedium is an independent bone of the foot. (marsupials).

2 In the human embryo the intermedium tarsi is laid down as a separate cartilage: it remains for a short time independent: it then unites with the tibiale to form the astragalus, and is recognisable as the posterior process of that bone.

3 The intermedium tarsi appears occasionally in the human adult as an independent bone.

In 1883 he put forward the hypothesis that the os trigonum was the homologue of the semilunar, i.e. it is the

os intermedium tarsi. He homologised the astragalus, minus its posterior process, with the scaphoid of the carpus. Thus the astragalus represents the scaphoid and semilunar of the manus.

Albrecht at first entertained a similar view to Bardeleben, but later he advocated the theory of the astragalus proper being the homologue of the lunatum, whilst the os trigonum equals the cuneiform. He makes the tibial sesamoid of Castor equal the tibiale: the astragalus equal the intermedia 1 & 2 : equal to the semilunar plus the pyramidal of the hand.

Baur believes that the os trigonum is merely the homologue of a sesamoid bone, but still he thinks that there may be a possibility of its representing the intermedium (lunatum). He states that a separated os trigonum cannot be demonstrated embryologically in any class of mammalia except the marsupials. He asserts farther, from an examination of a Didelphys embryo, that

the os trigonum appears secondarily from the astragalus. He makes out that if this be the case the astragalus must be the homologue of the intermedium. From an examination of rodentia, he says-

Tibial sesamoid = Tibiale
Astragalus (whole) = Intermedium
Os trigonum = Sesamoid.

Cope's description of the extinct reptile Pelycosauria supports him in this view, and he quotes the following statement, "in this (Pelycosauria) the questionable element (internal navicular) is in direct contact with the tibial face of the astragalus".

I am indebted to Sir William Turner for the suggestion of this subject, for the use of the literature employed in its compilation, and for the opportunity of doing the work in the University Anatomical Department.

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TARSUS.